Prediction of usable clutch life for utility vehicles in Indian driving conditions – A new approach

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***Abstract*—Prediction of product life is an important consideration in the product design. This helps to make product more robust, reliable & durable and also reduce the development lead time. Clutch is a wear & tear part in an automobile which cannot be avoidable and its performance is directly correlated with its useful life. There needs to be a design guideline which can help one to predict the usable clutch life considering driving conditions & vehicle parameters. In this paper, a methodology is formulated for the prediction of useful clutch life. Field data of 3-4 years on the selected utility vehicles has been used to capture the Indian driving conditions. With the help of data analysis, beta life for given vehicle configuration has been calculated using statistical approach. Based on statistical data analysis, a relation between the beta life & vehicle parameters has been captured & formulated which can be used as a guideline to predict usable clutch life in the design stage.Same methodology can be also adopted for Passenger car, SUV, pick up & commercial platform vehicles.**

Keywords –clutch life, statistical approach, clutch wear & tear, beta life, driving conditions, vehicle parameters.

I. Introduction

Achieving high product reliability has become increasingly important aspect for manufacturers in order to meet customer expectations among the threat of strong global competition. Poor reliability can fate a product and affect the reputation of a brand or company. Poor reliability also presents financial risks from warranty, product recalls. When developing new products, it is very much important that manufacturers develop reliability specifications and utilize methods to predict and validate that those reliability specifications will be met.Manufacturers invest considerable capitals in developing new products and services.Research studies play a important role in providing information about many aspects of a product or service.

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These aspects are effectiveness, safety, reliability, and ultimately its value to the prospective customer. Good design of these studies based on statistical techniques & analysis of the data which is generated, can save manufacturers time and expenses by providing accurate information in a timely manner, before the products are marketed.

In this paper focus is on the prediction of the usable clutch life considering the Indian driving conditions on the utility vehicles. Clutch life will differ based on the driving conditions. One will not get a same clutch life in India as well as in European countries. Definitely he will get less clutch life as Indian traffic conditions are dense compared to European countries. Road conditions are also different. Here Indian driving conditions are captured by collecting field data & it is correlated with the important vehicle parameters which can contribute to the clutch life.

II. Brief Description To Clutch

A Clutch is a mechanical member used to connect the driving shaft (engine side) to a driven shaft (transmission side), so that the driven shaft may be started or stopped as & when required, without stopping the driving shaft. A clutch thus provides an interruptible connection between two rotating shafts.A basic representation of the clutch is shown in fig. 1. A popularly known application of clutch is in automobiles where it is used to connect the engine and the gear box.. Clutches are also used extensively in production machinery of all types.

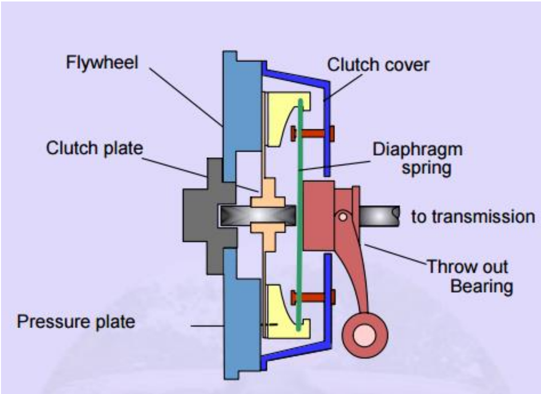

Fig 1:Clutch Layout

In an automobile clutch is a wear & tear part whose performance is directly correlated with its useful life. Clutch wear is happened due to the clutch slippage. This term is used when the driver consecutively applies and releases the clutch to achieve some movement of the car. It's called clutch slippage because the clutch plate will slipagainst the flywheel surface when such an action is performed. Clutch slippage is known to be hard on the clutch surface due to the sliding friction created. Clutch wear is directly related to the clutch life. Due to excessive clutch wear vehicle become not movable. This also increase the clutch release load & ultimately the clutch pedal effort. The release load is the clutch characteristics that is most noticeable to the vehicle operator. The release load is directly related to clutch pedal efforts. As the clutch pedal is depressed, pedal effort initially starts to increase. Then part way through the pedal stroke, the load begins to decrease. This is a unique characteristic of the diaphragm spring clutch. As the engagement of the clutch is gradual, there is a clutch slippage between the start of clutch engagement & full engagement. This time is called as clutch slip time. Due to this slippage there is heat generation between the flywheel, Clutch disc & pressure plate. If the slip time is more, heat generation will also be more. This heat generation will cause the clutch burning. Customer feels discomfort due to less clutch life &increase in clutch pedal effort. So, it is very important to know the probable clutch life in the design stage itself. This will help to make the product robust & reliable.

III. Literature Review

Matthew Watson et al. [1]presented a model based technique for the prediction of remaining useful life of clutch. This model considers the physical wear process, including debris particle& protective layer creation using parameters such as surface roughness, particle size & surface temperature. These stochastic variables areassessed in a probabilistic framework, using statistical approach such as Monte Carlo and importance sampling, which consider both measurement and modeling ambiguity. Confidence interval prognostic results are provided to predict the remaining useful life of the clutch throughout its limited life in near-real time. Monte carlo methods are used as a statistical simulation. In performing Monte carlo simulation however the system is assumed to be a stochastic process & random number simulation is therefore applicable.

Shaohua sun et al. [2]Based on the structural performance& working features of the dry clutch, this study focuses on the various aspects that affect the performance & life of the dry clutch. It has been proven that rise in temperature due to clutch slippage is major contributor. Here dynamic model is established for the dry clutch during launching. Frictional work which is generated during clutch operation ie. vehicle launching or during change of gear is simulated & calculated. In this paper the boundary conditions of the temperature field & the finite element model for the dry clutch was built. After examining the change in the temperature during frequent launching the vehicle some measures are proposed which can help to reduce the temperature of dry clutch in its design stage.

Gregori I et al. [3] studied DOE (Design of experiment) which is one of the statistical approach to find the solution. Generally it is observed that there is a large variation in the clutch life which is getting in the field. In field the clutch operation pattern is user dependent & also the condition in which the vehicle is operated. After failure of the clutch in an automobile one get a very little information about its use pattern & operating conditions. In this paper a test procedure is developed which will take care of all driving patterns & vehicle operating conditions. With the help of DOE all possible permutation & combinations are captured & a generalised test procedure is developed.

Samir Sfarni et al. [4] In this work, behaviour of the clutch disc assembly which allows a gradual engagement & disengament of torque transmission is studied. This is obtained by the friction of the clutch disc with flywheel. Clutch cushion curve is one of the important parameter for the gradual engagement & disengagement of the clutch. Here author has proposed to do a finite element analysis which will help to predict the clutch cushion curve. Author has also focused on the very much important parameter of the clutch failure ie. Clutch wear. In some cases clutch facing material is completed disintegrated & vehicle becomes not movable.

K Tataiah [5]In his work he solved a various partial differential equations of heat conduction to predict interface temperature at any time during the engagement of the clutch, using physical conditions that more closely approach those existing in the transmission.

IV. LITERATURE GAP

Matthew Watson et al. [1]In this paper dynamic model of wear based phenomena doesn’t consider any driving pattern which would have helped to simulate real life situation.

Shaohua sun et al. [2]In this paper the author has not considered any statistical approach.

Gregori I et al. [3]The test procedure which is been developed in this paper is based on the DOE. Here only one vehicle configuration is considered. So the test procedure may change if the vehicle specifications are changed.

Samir Sfarni et al. [4]Here comparative study with conventional clutch is presented, but one can find lag in the consideration of real time situation such as frequent clutch operation, traffic conditions etc.

V. STATISTICAL APPROACH

Statistical approach contributes to the product development cycle in numerous important ways:

- Design and analysis of individual experiments, field tests / validation and surveys
- Synthesis of research results from multiple studies
- Development of statistically-based systems for prediction, classification and diagnosis

Statistical science is a part of reliability engineering. Reliability engineering is the discipline of confirming that the product will be reliable when operated in a specific manner. In other words, the function of reliability engineering is to avoid failures. Reliability, engineering is implemented by taking structured and possible actions that maximize reliability & minimize the effects of failure. In general, three steps are essential to achieve this objective. The first step is to build maximum reliability in to the product during the design & development stage. This step is most critical in that it determines the inherent reliability. The second step is to minimize production process discrepancy to assure that the process does not appreciably degrade the inherent reliability. Once the product is deployed, appropriate maintenance operation should be initiated to alleviate performance degradation & prolong product life.

In this paper statistical approach has helped to know the clutch life distribution in the field. It has also helped to know the no. of clutch replacement per thousand vehicles. Weibull analysis has been used to find the clutch life distribution and beta life.

VI. PROBLEM STUDY

In field the automobile clutches face below problems

Slippage / Burning

Chatter

Noise

Vibration

High pedal Effort

In this paper area of interest is clutch slippage & burning. Due to excessive clutch slippage clutch gets worn out & vehicle becomes not movable or sometime customer feels low pick up.

The difference between the new & failed samples is shown in fig. 2 & fig. 3figure. One can observe the burning marks in the clutch disc as well as pressure plate. The metallic gray colour of new clutch has changed to the bluish. This colour change shoes the heat generation is excess

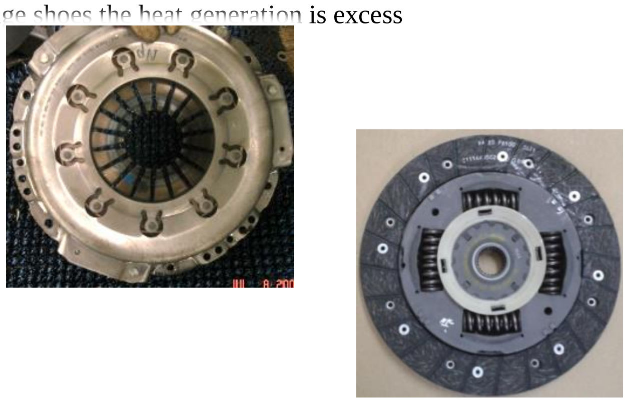

Fig 2: New Clutch

Fig. 3: Burnt clutch

VII. Objectives

- To capture & formulate a correlation between clutch life & vehicle parameters in terms of heat stress.
- To capture & formulate a correlation between clutch IPTV & vehicle parameters in terms of heat stress.
- Validate the correlation on rig level / bench level.

VIII. Methodology

As clutches are failing in the field it is very much important to collect the actual data from the field. It also requires to visit the field where actual clutches are failed to know the scenario such as driving conditions, traffic conditions, driving pattern, driving cycles etc.

As the collected data is very vast one need to follow a systematic approach to get the desired solution. A number of activities are required to be done in a systematic way such as field data collection, data analysis, statistical study & study of vehicle parameters contributing clutch wear & burning etc. A methodology which is been followed in this paper is shown in fig.4.

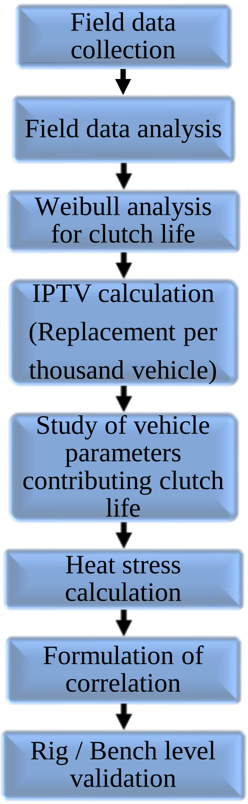

Fig. 4: Methodology

IX. Field Data Collection

In this paper utility vehicle platform is considered. Four vehicles having different vehicle specifications are taken. Vehicle wise specifications are shown in table 1

<table>
<tr><th>Sr. No.</th><th>Vehicle Model</th><th>Engine Torque (Nm)</th><th>clutch Dia (mm)</th><th>1'st Gear ratio</th><th>Axle ratio</th><th>DTR (mm)</th><th>GVW (Kg)</th></tr>
<tr><td>1</td><td>Vehicle A</td><td>180</td><td>228 X 150</td><td rowspan="3">4.1</td><td>4.63</td><td rowspan="2">349</td><td>2540</td></tr>
<tr><td>2</td><td>Vehicle B</td><td>223</td><td>240 X 160</td><td>3.73</td><td rowspan="2">2600</td></tr>
<tr><td>3</td><td>Vehicle C</td><td>250</td><td>240 X 170</td><td>3.36</td><td rowspan="2">340</td></tr>
<tr><td>4</td><td>Vehicle D</td><td>115</td><td>228 X 150</td><td>3.87</td><td>5.37</td><td>2540</td></tr>
</table>

Table 1: Vehicle models & their specifications

Field failure data of all above vehicle models are collected & it has been observed that the high number of clutch failures (Clutch slippage / Burning) in the cities like Bengaluru & Kolkata. Refer fig. 5

The cities like Bengaluru are having very dense traffic conditions, frequent traffic jam conditions & bumper to bumper traffic. Here vehicles needs frequent start –stop operation. Sometimes drivers launch the vehicles in 2nd gear which leads to the more slippage & more clutch burning problems. The above conditions results in clutch overload leading to higher operating temperature & therefor faster clutch facing wear.

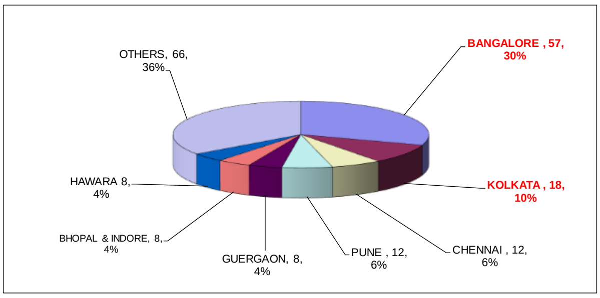

Fig. 5: Citywise distribution

To summarise the problem below are some notable points.

- Failure Pattern - Clutches are burning.
- Customer complaint – Vehicle not moving / Low pick up.
- Driving patterns in cities like Bengaluru& Kolkata were not captured.

This failure could have reduced if clutch life is predicted in the design stage itself considering Indian driving conditions.

Here it is requiredto build some correlation between clutch life with vehicle parameters which can contribute clutch to operate at high temperature.

X. Statistical Data Analysis

Based on the field data of clutch failures for the given vehicle models,the no. of instances i.e. failures per thousand vehicles are calculated. Table 2 gives no. of replacements per thousand vehicles.

Sr. No.	Vehicle Model	Replacement per thousand
1	Vehicle A	5.6
2	Vehicle B	17.89
3	Vehicle C	189
4	Vehicle D	4

Table 2: No. of replacement per thousand vehicles

Also Beta life of the clutch for all the vehicle model are calculated. The Beta life metric originated in the ball and roller bearing industry, but has become a metric used across a variety of industries today. It's particularly useful in establishing warranty periods for a product. The "BX" or "Bearing Life" nomenclature, which refers to the time at which X% of items in a population will fail, speaks to these roots.

So if suppose BX =B10 then, B10 life is the time at which 10% of units in a population will fail. Alternatively, you can think of it as the 90% reliability of a population at a specific point in its lifetime or the point in time when an item has a 90% probability of survival. The B10 life metric became popular among ball and roller bearing makers due to the industry's strict requirement that no more than 10% of bearings in a given batch fail by a specific time due to fatigue failure.

Based on the field data which is collected for the given vehicle models various beta life has calculated for the analysis purpose which are as below table 3.

Sr. No.	Vehicle Model	B(10)	B(5)	B(3)	B(1)	B(0.3)	B(0.1)
1	Vehicle A	820500	399500	237500	78500	23400	7800
2	Vehicle B	183000	95000	59000	21500	7200	2600
3	Vehicle C	27500	14000	8500	3000	900	300
4	Vehicle D	64000	36000	23500	9500	3700	1550

Table 3: Vehicle models & their respective beta life

Parallely, field verbatim is for the clutch life is collected for respective vehicle models which are as below,

Sr. No.	Vehicle Model	Field Verbatim	Corresponding "B" life
1	Vehicle A	35K - 40K	**B(0.48)**
2	Vehicle B	35K-40K	**B(1.84)**
3	Vehicle C	10K- 15K	**B(4.5)**
4	Vehicle D	24K	**B(0.8)**

Table 4: Vehicle models & their respective field verbatim & corresponding beta life

The average corresponding beta life for above field verbatim is coming out to be B(2).B(2) life for all the models are calculated in table 5.

Sr. No.	Vehicle Model	B(2) Lac Kms
1	Vehicle A	1.57
2	Vehicle B	0.405
3	Vehicle C	0.06
4	Vehicle D	1.62

Table5: Vehicle models & their B(2) life

XI. Vehicle Parameters Contributing Heat Stress.

In order to have a mathematical solution & consistency in calculation certain assumptions are required.

1. It is assumed that the Engine speed is constant.
2. The torque transmitted during the launch is constant, which causes constant acceleration
3. Disregard the elasticity of the Drivetrain
4. Disregard the Thermal Influences
5. Resistance Torque is Constant
6. Startup occurs from Vi = 0
7. Energy absorbed by the clutch system is assumed to be half of the expended energy during startup.

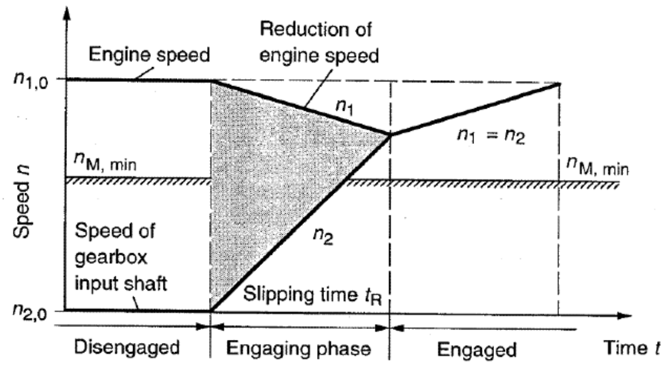

Fig. 6: Effect of clutch engagement on engine & gear box speed

Fig. 6 shows the effect of clutch engagement on engine & gear box speed.

$$P = \frac{2\pi NT}{60}$$

Where,
P = Power in Watt (1 Watt = 1 Joule/Sec)
N = Rotational speed in RPM
T = Torque in Nm

As, $Power = \ Energy\ /\ Sec$

$$Energy\ /\ Sec = 2\pi N\ X\ (Te)$$

$$Energy = 2\pi N\ X\ (Te) X\ (Ts)/60\ \ in\, Joule$$

Where (ts) = Slip Time in Sec

$$(ts) = I\ X\ \omega/(Te - Tw)$$

Where,

I = Vehicle Reflected Inertia at Input Shaft in N.m2
ω = Angular Velocity of Engine in Rad / Sec
Te = Engine Torque in Nm
Tw = Reflected Toque of Wheel on Input Shaft

$$I = \frac{GVW\ X\ DTR^2}{(ig\ X\ ir)^2}$$

Where,

GVW = Gross Vehicle Weight in N
DTR = Dynamic Tyre Radius in m
ig = 1st Gear Ratio
ir = Rear Axle / Final Drive Ratio

$$\omega = \frac{2\pi N}{60}$$

Where,

N = Engine Rotational speed in RPM

$$Tw = \frac{\mu\ X\ GVW\ X\ DTR}{(ig\ X\ ir)}$$

Where,

μ = Co-efficient of Rolling Resistance (0.1)
GVW = Gross Vehicle Weight in N
DTR = Dynamic Tyre Radius in m
ig = 1st Gear Ratio
ir = Rear Axle / Final Drive Ratio

As,

$$ts = \frac{I\ X\ \omega}{(Te - Tw)}$$

$$= \frac{\frac{GVW\ X\ DTR^2}{(ig\ X\ ir)^2}\ X\ \frac{2\pi N}{60}}{Te - \frac{\mu\ X\ GVW\ X\ DTR}{(ig\ X\ ir)}}$$

$$= \frac{GVW\ X\ DTR^2\ X\ 2\pi N}{(ig\ X\ ir)^2\ X\ 60}\ X\ \frac{1}{Te - \frac{\mu\ X\ GVW\ X\ DTR}{(ig\ X\ ir)}}$$

Putting this value of ts in energy formula,

$$Energy = \frac{2\pi(Te) X\ (ts)}{60} in\ joule$$

$$= \frac{2\pi N(Te)}{60}\ X\ \frac{GVW\ X\ DTR^2\ X\ 2\pi N}{(ig\ X\ ir)^2\ X\ 60}\ X\ \frac{1}{Te - \frac{\mu\ X\ GVW\ X\ DTR}{(ig\ X\ ir)}}$$

$$= \frac{(2\pi)^2\ X\ N^2\ X\ Te\ X\ GVW\ X\ DTR^2}{3600\ X\ (ig\ X\ ir)^2\ X\ (Te - \frac{\mu\ X\ GVW\ X\ DTR}{(ig\ X\ ir)}}$$

$$\boldsymbol{Energy} = \frac{(2\pi)^2 \times (N/100)^2 \times 10000 \times T_e \times GVW \times DTR^2}{3600 \times (ig \times ir) \times [(T_e \times ig \times ir) - (\mu \times GVW \times DTR)]}$$

$$\boldsymbol{Clutch\ frictional\ area} = \frac{2\pi \times (OD^2 - ID^2)}{400}$$

$$\boldsymbol{Workdone\ or\ Heat\ stress} = \frac{Energy}{Frictional\ Area}$$

XII. Formulation Of Correlation

Here heat stress values for all the models are calculated. A correlation between Heat stress, no. of replacement per thousand & B(2) life of a clutch are built.

Sr. No.	Vehicle Model	Heat Stress (J/Cm^2)	Replacement per thousand	B(2) Lac Kms
1	Vehicle A	23.8	5.6	1.57
2	Vehicle B	34.7	17.89	0.405
3	Vehicle C	45.1	189	0.06
4	Vehicle D	19.2	4	1.62

Table 6: Vehicle models & there corresponding heat stress, replacement per thousand & B(2) life

Table 6 gives the vehicles & their respective values of heat stress, no. of replacement per thousand vehicle & B92) life.

A. Correlation between heat stres & no. of replacements per thousand.

Plot of heat stress Vs No. of replacement per thousand is as below.

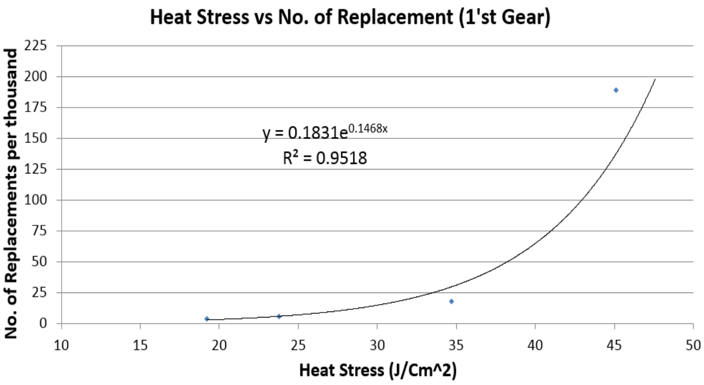

Fig. 7: No. replacement per thousand Vs heat stress plot

Here exponential correlation between heat stress &No. of replacement per thousand is getting. Coefficient of correlation R = 0.9756 indicating a very strong correlation.

A generalise formula is as below

$$Y = 0.1831e^{0.1658X}$$

Where,

Y = No. of Replacement per thousand vehicle

X = Heat stress (J/Cm^2)

B. Correlation between heat stres &clutch life

Plot of heat stress Vs beta life (B2.5) is as below.

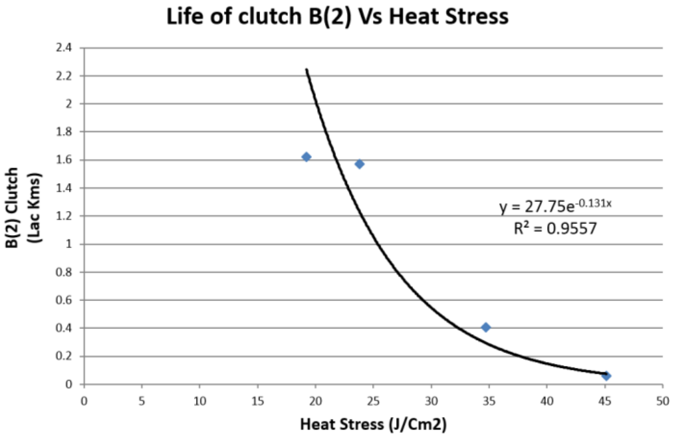

Fig. 8: B(2) clutch life Vs heat stress plot

Here exponential correlation between heat stress & beta life of a clutch is getting. Coefficient of correlation R = 0.9776 indicating a very strong correlation.

A generalise formula is as below

$$Y = 27.75e^{-0.131X}$$

Where,

Y = Clutch life B2.5 (Kms)

X = Heat stress (J/Cm^2)

XIII. INFERENCE

- Above relation shows that there is a strong correlation between heat stress clutch life & no. of replacements. One can use the above relations as a guideline for selecting a clutch for a similar utility vehicle application.
- Let us say that one intend to have no. of clutch replacements per thousand as 7then the expected heat stress should be less than or equal to $25J/Cm^2$.
- Taking this analogy forward the formula generated for beta 2 can be used for predicting the clutch life. So for heat stress of value $25J/Cm^2$, B2 will be 1.2 Lac Km
- Consider vehicle C which is having highest no. of clutch failures & less clutch life. Vehicle C is having B(2) life as 6000 Kms. If one wants to increase the B(2) life by 5 times ie. To make it 30000 Kms, it is required to have heat stress in the range of ~30 to 3 J/Cm^2.

XIV. VALIDATION

These correlations can be validated on clutch dynamometer rig. The actual clutch operation is simulated on the test rig.'Vehicle C' having highest no. of failures & lowest clutch life is selected for the validation purpose.

In existing configuration, 'vehicle C' having heat stress of 45.1 J/Cm^2 is getting B(2) clutch life as 6000 Kms. Suppose one want to increase the B(2) life of the clutch by 5 times ie. 30,000 Kms. Graph from fig. (6) shows that to have B(2) clutch life as 30,000 Kms, heat stress should be 33-34 J/Cm^2.

This can be achieved by increasing either by clutch size / 1st gear ratio / Axle ratio or by decreasing DTR / GVW. (Refer formula for heat stress in section X)

For validation option of increasing the clutch size from dia 240 mm to dia 260 mm as below is selected.

Vehicle Model	Engine Torque (Nm)	clutch Dia (mm)	1'st Gear ratio	Axle ratio	DTR (mm)	GVW (Kg)	Heat Stress (J/Cm^2)
Vehicle C (Existing)	250	240 X 170	4.1	3.36	340	2600	45.1
Vehicle C (Proposed		260 X 170					33.8

Table 7: Current & new proposal of vehicle C

Test specifications are given in table 8.

Test Description	Test Conditions
Clutch dynamometer test	Target Cycles : 70000 Cycles Inertia : 3.2 Kg-m^2 Bearing Travel - 9mm Pedal Travel - 145 mm

Table 8: Test specification

The clutch dynometer layout is shown in fig. 9. It is a replication of the actual driveline in the vehicle.

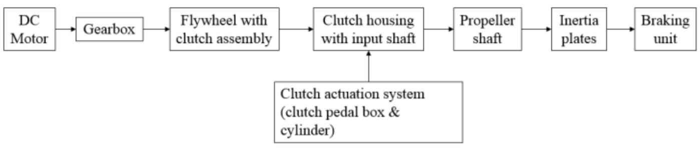

Fig. 9: Clutch dynometer layout

It consist of a DC motor having RPM as3000 to which a gear box is attached so that RPM is reduced to 1500. At this RPM the clutch is generally engaged during vehicle launching. Clutch assembly along with flywheel & clutch release bearing is mounted after gear box. To operate the clutch, Clutch actuation system consisting of clutch pedal box & cylinder is attached. Inertia plates are attached to simulate the vehicle reflected inertia from the wheel to clutch followed by braking system.

After completion of experimental set up clutch dynometer is first run along with dia 240 clutch and clutch wear is measured after interval of every 10K till the completion of 70K cycles. Refer table 9. After completion of dia 240 clutch, dia 260 clutch is fitted. Same cycle is carried out & clutch disc wear is measured after same interval. Values of both clutch disc wear & no. of cycles are tabulated as below. A graph of Clutch disc wear Vs no. of cycles is plotted which shows that life has improved approximately by 5 times. Refer fig. 10. This validates the analytical results.

No. of cycles	**Clutch disc wear (Dia 240 Current)**	**Clutch disc wear (Dia 260 Proposed)**
0	0	0
10000	0.55	0.25
20000	0.7	0.3
30000	0.8	0.38
40000	0.86	0.42
50000	0.95	0.5
60000	1.05	0.6
70000	1.1	0.7

Table 9: Clutch disc wear & no. of cycles

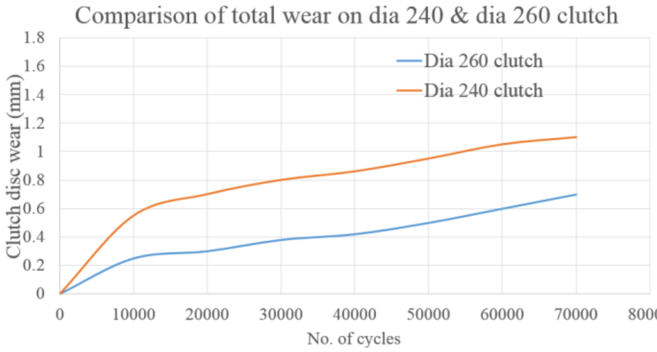

Fig. 10: clutch disc wear Vs No. of cycles plot

XV. Results & Discussion

From the above graph it is observed that to complete 70,000 cycles, clutch wear is very less for dia 260 compared with dia 240.

Clutch wear (mm)	No. of cycles covered by dia 240 clutch	No. of cycles covered by dia 260 clutch
0.7	15,000	70,000

Table 10: Comparative no. of cycles & clutch disc wear

Here in table 10 it is observed that with clutch disc wear of 0.7 mm, dia 260 clutch has covered 70K cycles & dia 240 clutch has covered only 15K cycles. It is observed that for the same value of clutch disc wear dia 260 clutch has covered by 4 times more cycles than dia 240. So one can use the analytical formula generated in section XI as below,

$$Y = 27.75e^{-0.131X}$$

Where,

Y = Clutch life B2.5 (Kms)

X = Heat stress (J/Cm^2)

This will become a design guideline to set the clutch life in the design stage itself which will save warranty cost & improve product quality & reliability.

XVI. Conclusion

The correlation which isbuilt between heat stress & clutch life will help to predict the probable clutch life of a given vehicle configuration in advance. This correlation will also guide to manipulate the vehicle parameters such as clutch size, gear ratios, axle ratio, DTR & GVW to achive the desired clutch life. This can be used as a guideline for clutch life rin utility vehicle platform.

Similar methodology can be adopted for the commercial vehicle.

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