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Reliability Analysis of Moulded Case Circuit Breaker Mechanism Based On Stress Strength Interference with Degradation Analysis

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Abstract— This paper presents reliability prediction of Moulded Case Circuit Breaker (MCCB) mechanism based on Stress Strength Interference (SSI) with degradation analysis. In degradation considered stress acting on component is constant and strength of component is reduced with respect to number of operating cycles. Identify the number of components in mechanism with their failure modes for accurate reliability analysis also find various stresses acting on the component out which for reliability analysis considered the maximum stress acting on the component. The reliability analysis of MCCB mechanism components are carried out in three intervals of operating cycles like 10000cycles, 20000cycles and 30000cycles. The main objective of this paper is to predict reliability of system when the system in design and development stage. The SSI degradation model is used to calculate degradation in strength of MCCB mechanism components with respect to number of operating cycles. At the end of this paper, reliability of mechanism is predicted from the reliability of mechanism components for thee intervals.

Key words— **Analytical method, degradation model, failure modes, reliability analysis, stress analysis.**

I. INTRODUCTION

Moulded Case circuit Breaker is mostly designed to protect system from low voltage distribution. MCCB consist by various subsystems like operating mechanism, Trip system and Arc quenching system out of those subsystems the operating mechanism is main subsystem of MCCB and most of the failures are introduced in operating mechanism of MCCB, so it's important to do reliability analysis of MCCB mechanism in design and development stage to decide various strategies for warranty and maintenance. Also from literature it is came to know there is 90% failure introduced in MCCB due to failures are introduced in operating mechanism. The various functions of MCCB are achieved by using operating mechanism. The various components of operating mechanism are motioned in Table I. The requirement of the mechanism is to perform various functions of MCCB with quick and instant of time and to perform those functions by mechanism the torsion extension spring is used. The torsion extension spring exert force on the various components of mechanism in various directions so design of various components is done based on spring force.
Reliability is defined as the ability of a system or component to perform its required functions under stated conditions for a specified period of time (IEEE; 1990). The stress strength interference (SSI) model has been widely used for reliability analysis of mechanical components. The concept of stress-strength in engineering devices has been one of the deciding factors of failure of the devices. It has been customary to define safety factors for longer lives of systems in terms of the inherent strength they have and the external stress being experienced by the systems. If Xo is the fixed strength and Yo is the fixed stress, that a system is experiencing, then the ratio Xo/ Yo is called safety factor or factor of safety and the difference of Xo - Yo is called safety margin. Thus in the deterministic stress-strength situation the system survives only if the safety factor is greater than 1 or equivalently safety margin is positive.
There are appliances (every physical component possesses an inherent strength) which survive due to their strength. These appliances receive a certain level of stress and sustain. But if a higher level of stress is applied then their strength is unable to sustain and they break down. The term stress is defined as failure inducing variable and also it is defined as stress (load) which tends to produce a failure of a component or of a device of a material. The term load may be defined as mechanical load, environment, temperature and electric current etc. The term strength is defined as the ability of component, a device or a material to accomplish its required function (mission)

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satisfactorily without failure when subjected to the external loading and environment therefore strength is failure resisting variable. Stress-strength model is defined as the variation in 'stress' and 'strength' results in a statistical distribution and natural scatter occur in these variables when the two distributions interfere.

In further investigations concerning to calculate components reliability based on the SSI model. Therefore effort have been taken by many researchers, established Discrete Stress Strength Interference Model for Reliability Analysis Under Multi-operating Conditions [1], the algorithm is developed for computing the unreliability bounds based on an improved Monte Carlo method [2], estimate a time to failure distribution using degradation analysis [3], mathematical model is developed to calculate exact truncated exponential and power function strength with normal stress in SSI [4], presents the reliability computation based on Bayesian estimation and stress strength Mukherjee Islam Failure Model [5], reliability estimation of system based on SSI model [6], dynamic reliability models of mechanical components with the failure mode of fatigue are developed based on equivalent strength degradation paths, whose uncertainty is determined by both the distribution of material parameters and the distribution of load, reliability analysis by considering fatigue stress and statistical inference solved by finite element analysis and Monte Carlo simulation [7].

II. DEGRADATION MODEL

There are four degradation models available for reliability analysis. Those are linear, exponential, power and logarithmic. A power degradation model is typically seen in situations where the level of the mean rate of wear is monotonically decreasing. Evidence of this is seen in processes where there is an accumulation of fatigue in metals, accumulation of deformation, corrosion, diffusion of one chemical in another and various other chemical processes. While, a decreasing degradation model is often counterintuitive when considering processes of fatigue and crack growth especially in the zone of catastrophic wear (one of three zones in a typical wear cycle), consider the situation where the level of Al2O3 in Al serves as an indicator of degradation in terms of loss in hardness and density. Here, when pure aluminium is subject to oxidation, Al2O3 forms a surface layer that hinders the rate of oxidation hence causing the rate of drop in hardness to monotonically decrease. Similarly, many such processes in the field of pharmacokinetics indicate a power degradation model. A power degradation model is represented in equation (1)

$$S(t) = S_0(1+\alpha t)^{-\beta} \qquad (1)$$

Where, S(t) is the value of tensile strength at time "t" and is the initial inert strength.

Parameters α & β are constant values equal to 0.010169 and 0.004011, respectively, when tested under relative humidity of 50% and determined by means of nonlinear regression [8].

III. ANALYTICAL METHOD

The stress-strength interference model is one analytical method used to compute reliability of system or component. It is found to be useful in situations where the reliability of a component or system is defined by the probability that a random variable Y (representing strength) is greater than another random variable X (representing stress). Any state of component where Y falls below X represents the component to be in unacceptable state or to have failed. Once the distribution and parameters of X and Y are determined, the reliability can be calculated by estimating the probability X<Y, which is computed by equation (2)

$$R = \int_{-\infty}^{\infty}\int_{Y}^{\infty} f(x)f(y)\,dx\,dy \qquad (2)$$

Where, f(x) is the probability density function (pdf) of stress (X) and f(y) is the probability density function (pdf) of strength (Y). Analytical model to calculate reliability based on SSI by considering degradation model which is shown in equation (3)

$$R(t) = \int_{X}^{\infty} \frac{1}{\sqrt{2\pi}\sigma(t)} \times e^{-\frac{1}{2}\left(\frac{X-\mu(t)}{\sigma(t)}\right)^2} dx \qquad (3)$$

where,

$\sigma(t) = \sigma_0(1+\alpha t$ = standard deviation of the Strength at time 't'

$\mu(t) = \mu_0(1+\alpha t$ = mean of the strength at the time 't'

μ_0 = mean of the initial stregth distributin

σ_0 = standard deviation of the initial stregt

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IV. FAILURE MODE

To increase the reliability of component or system in design stage it is essential to find the various possible failure modes of component or system. But in practical there must be more than one failure mode for each component like upper link have bending, shear, and bearing failure modes those are shown in Table I. Out of those failure modes the design is done based on the most critical failure mode to reduce the frequency of failure. The reliability of system is purely depends on their components that's why for reliability analysis of MCCB mechanism there must know the number of components of MCCB mechanism so Table I represents the number of components in mechanism with their possible failure modes. Those failure modes have been decided from the geometry of components and the direction of force acting on the components. In Table I 'Y' represents failure mode is present in component and 'N' represents absence of failure mode. $\sigma_b, \tau, \sigma_c, \sigma_{be}, \sigma_{buc}$ are represents bending, shear, crushing, bearing, buckling failure modes respectively.

Table I: Number of components in MCCB mechanism with possible failure modes

Sr. No.	Name of Components	Types of failure modes				
		σ_b	τ	σ_c	σ_{be}	σ_{buc}
1	Upper link (UL)	Y	Y	N	Y	Y
2	Lower link	Y	Y	Y	Y	Y
3	Latch link (LL)	Y	Y	Y	Y	N
4	Fork	Y	Y	N	N	Y
5	Floating pin	Y	Y	N	Y	N
6	Latch Bracket (LB)	Y	Y	Y	Y	N
7	LB pivot pin	Y	Y	N	Y	N
8	Trip Plate (TP)	Y	Y	N	Y	Y
9	TP pivot pin	N	N	N	Y	N
10	UL pivot pin	Y	Y	N	Y	N
11	LL pivot pin	Y	Y	N	Y	N

V. STRESS ANALYSIS

In stress strength inference model stress analysis plays a very vital role and which is very useful for reliability analysis in design stage. Stress analysis is nothing but analysis the effect of various loads acting on the various components of MCCB mechanism. In MCCB mechanism the load acting on various components is due to torsion extension spring. The intensity of spring force is varying with respect to position of spring and the various positions of spring are ON, OFF, and Trip positions. From analysis of MCCB mechanism it is came to know that in ON position the spring exerted higher force on the component upper link pivot pin so the stress calculation is done for maximum force. Similarly all stress calculations are carried out for other components of MCCB mechanism and the results of calculations are shown in Table II. The calculation of various stresses acting on the components is done based on the maximum bending moment equation and those values are verified on Pro-E software with Pro-Mechanical analysis. According to the stress calculation of components the material selection is done to ensure the factor of safety (FOS). The maximum stress acting on component, strength of component and FOS are listed in Table II. Form stress analysis and material selection the factor of safety of all components is greater than one means the reliability of system is achieved in design stage of system.

Table II: Represents tensile strength and maximum stress of various components of MCCB mechanism

Sr. No.	Name of Components	Tensile strength (N/mm^2)	Max. stress (N/mm^2)	FOS
1	Upper link (UL)	2000	345.577	5.787
2	Lower link	2000	117.479	17.024
3	Latch link (LL)	2000	92.4376	21.636
4	Fork	2000	507.545	3.940

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5	Floating pin	790	82.872	9.532
6	Latch Bracket (LB)	585	59.367	9.853
7	LB pivot pin	585	36.923	15.843
8	Trip Plate (TP)	440	9.5511	46.067
9	TP pivot pin	540	27.196	19.855
10	UL pivot pin	505	37.445	13.486
11	LL pivot pin	420	55.648	7.547

VI. RELIABILITY ANALYSIS

Reliability analysis is carried out by degradation model while analysis consider the stress acting on component is constant and strength of component is decreasing with respect to numbers of operating cycles. Reliability analysis is done in three intervals those are 10000cycles, 20000cycles and 30000cycles. The degradation model is used to calculate degradation in strength of components, which is mentioned in equation (1) to show the calculation and results one component is selected from mechanism i.e. fork. The results of degradation in strength of fork for 30000cycles is shown in Table III, similarly the calculation is carried out for 10000cycles and 20000cycles. By same way the degradation analysis is done for each component of MCCB mechanism out of those some selected components are represented graphical in Fig.1, Fig.2, Fig.3 and Fig. 4 respectively. The sample calculation is shown below to get the idea of degradation calculation.

$$\mu_Y(t) = \mu_{Y_0}(1 + \alpha t)^{-\beta}$$

$\mu_Y(t)$ = Strength of component at time‘t’,
μ_{Y_0} = Initial strength of component

$$\mu_Y(1000) = 2000(1 + (0.010169 \times 1000)^{-0.004011} = 1967.49\ \mathrm{N/mm^2}$$
$$\mu_Y(2000) = 1967.49(1 + (0.010169 \times 2000)^{-0.004011} = 1923.969\ \mathrm{N/mm^2}$$

Table III: Represents Degradation in strength for constant stress of fork

Sr. No.	Number of cycles	Strength(Y)	Stress(X)	Y-X	Sr. No.	Number of cycles	Strength(Y)	Stress(X)	Y-X
1	0	2000	507.546	1492.454	17	16000	1158.491	507.546	650.945
2	1000	1967.49	507.546	1459.944	18	17000	1109.638	507.546	602.092
3	2000	1923.969	507.546	1416.423	19	18000	1062.237	507.546	554.691
4	3000	1874.386	507.546	1366.84	20	19000	1016.309	507.546	508.763
5	4000	1821.106	507.546	1313.56	21	20000	971.8656	507.546	464.3196
6	5000	1765.542	507.546	1257.996	22	21000	928.9107	507.546	421.3647
7	6000	1708.641	507.546	1201.095	23	22000	887.4393	507.546	379.8933
8	7000	1651.079	507.546	1143.533	24	23000	847.4403	507.546	339.8943
9	8000	1593.362	507.546	1085.816	25	24000	808.8978	507.546	301.3518
10	9000	1535.874	507.546	1028.328	26	25000	771.791	507.546	264.245
11	10000	1478.915	507.546	971.369	27	26000	736.0956	507.546	228.5496
12	11000	1422.722	507.546	915.176	28	27000	701.7842	507.546	194.2382

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13	12000	1367.478	507.546	859.932	29	28000	668.827	507.546	161.281
14	13000	1313.332	507.546	805.786	30	29000	637.1922	507.546	129.6462
15	14000	1260.396	507.546	752.85	31	30000	606.8461	507.546	99.3001
16	15000	1208.76	507.546	701.214					

From degradation analysis is observed high degradation in strength of component. But till 30000cycles the strength of component is greater than stress acting on component so there is less chance of component failure. After calculation of degradation for various components to calculate reliability some more calculation is required like calculate mean of strength, standard deviation of strength those calculations are shown below for fork which is the component of MCCB mechanism. Now for 30000cycles data is obtained for component fork that is shown in Table.III that data is used to calculate the mean and standard deviation of strength of fork similarly for other components of mechanism the mean and standard deviation is calculated for 10000cycles, 20000cycles and 30000cycles respectively by same method, from those results the failure probability and reliability is calculated for operating cycles those results are shown in Table IV also same results shown graphically in Fig. 5. Reliability is calculated with the help of equation (3) which gives reliability of component

$$R(t) = \int_{X}^{\infty} \frac{1}{\sqrt{2\pi}\sigma(t)} \times e^{-\frac{1}{2}\left(\frac{X-\mu(t)}{\sigma(t)}\right)^2} dx$$

where ,

$x = 507.546\ N/mm^2$

$\mu(t) = \text{Mean of Strength} = 1251.833\ N/mm^2$

$\sigma(t) = \text{Standard Deviation of Strength} = 443.1951\ N/mm^2$

$$R(30000) = \int_{507.546}^{\infty} \frac{1}{\sqrt{2\pi}\,(443.1951)} \times e^{-\frac{1}{2}\left(\frac{X-1251.833}{443.1951}\right)^2} dx = 0.953701$$

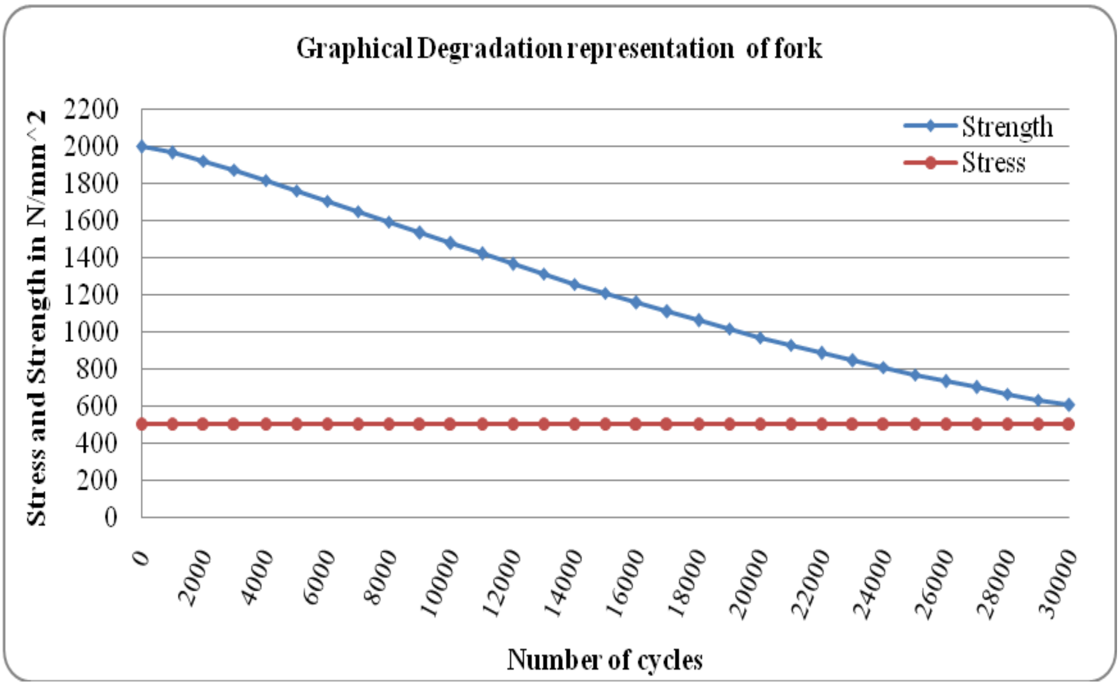

Fig.1 Degradation analysis for fork

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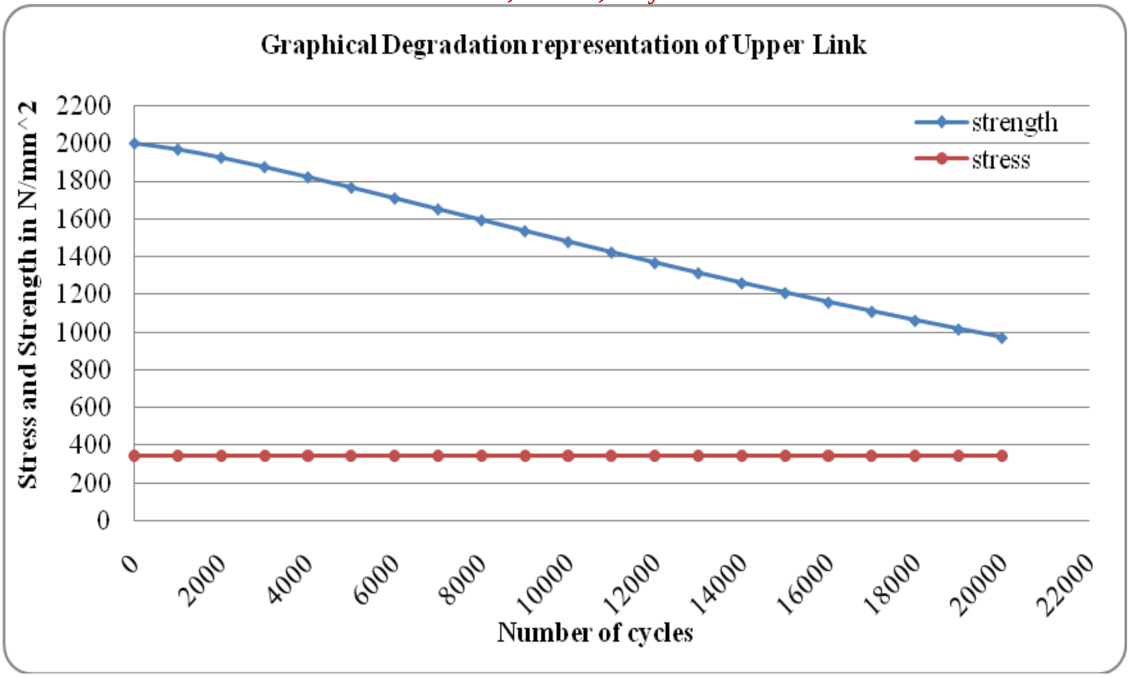

Fig.2 Degradation analysis for upper link

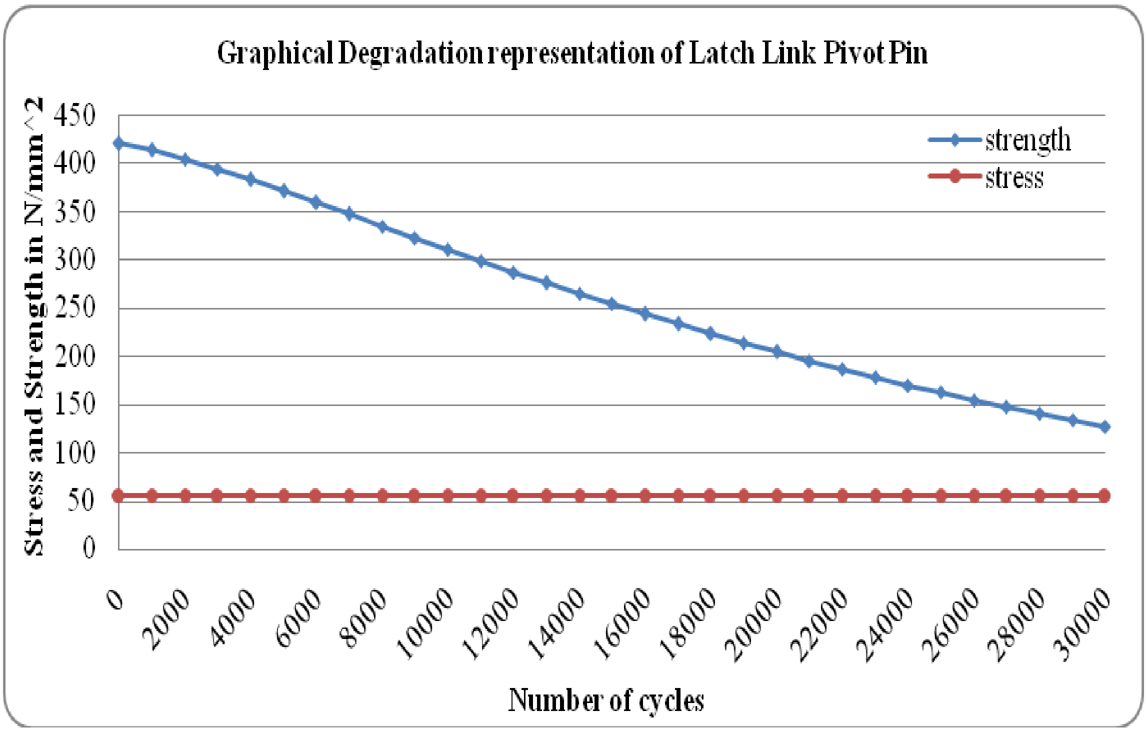

Fig.3 Degradation analysis for Latch link pivot pin

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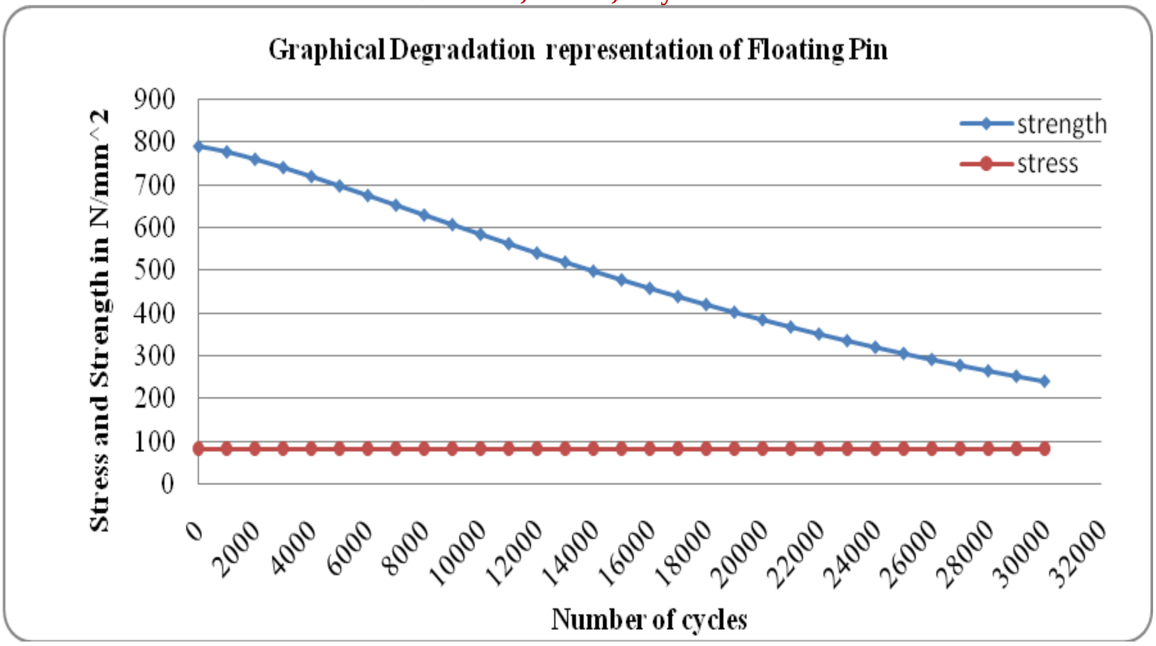

Fig.4 Degradation analysis for Floating Pin

Table IV: Reliability of MCCB components for various cycles

Sr. No.	Name of component	R(10000)	R(20000)	R(300000)
1	Upper link (UL)	1.00025	0.999954	0.979812
2	Lower link	1.00025	1.00023	0.995804
3	Latch link (LL)	1.00025	1.00025	0.995011
4	Fork	1.00025	0.99863	0.953701
5	Floating pin	1.00025	1.00019	0.99084
6	Latch Bracket (LB)	1.00025	1.0002	0.991275
7	LB pivot pin	1.00025	1.00013	0.994705
8	Trip Plate (TP)	1.00025	1.00025	0.997053
9	TP pivot pin	1.00025	1.00024	0.995554
10	UL pivot pin	1.00025	1.00023	0.993864
11	LL pivot pin	1.00025	1.00013	0.987265

Reliability of MCCB mechanism is depends on the components of mechanism so if any one component of mechanism is failed then mechanism failed to perform their desired functions, from this it is concluded that the mechanism followed the series configuration which is explained below by calculating reliability of mechanism for 30000cycles similarly the reliability of mechanism is calculated for 20000cycles and 10000cycles which is shown graphically in Fig. 6

$$R_{mech}(30000) = 0.995804 \times 0.979812 \times 0.995011 \times 0.953701 \times 0.99084 \times 0.991275 \times 0.994705 \times 0.997053 \times 0.995554 \times 0.993864 \times 0.987265$$

$$R_{mech}(30000) = 0.881033642$$

$$R_{mech}(20000) = 1.000432954$$

$$R_{mech}(10000) = 1.0027534$$

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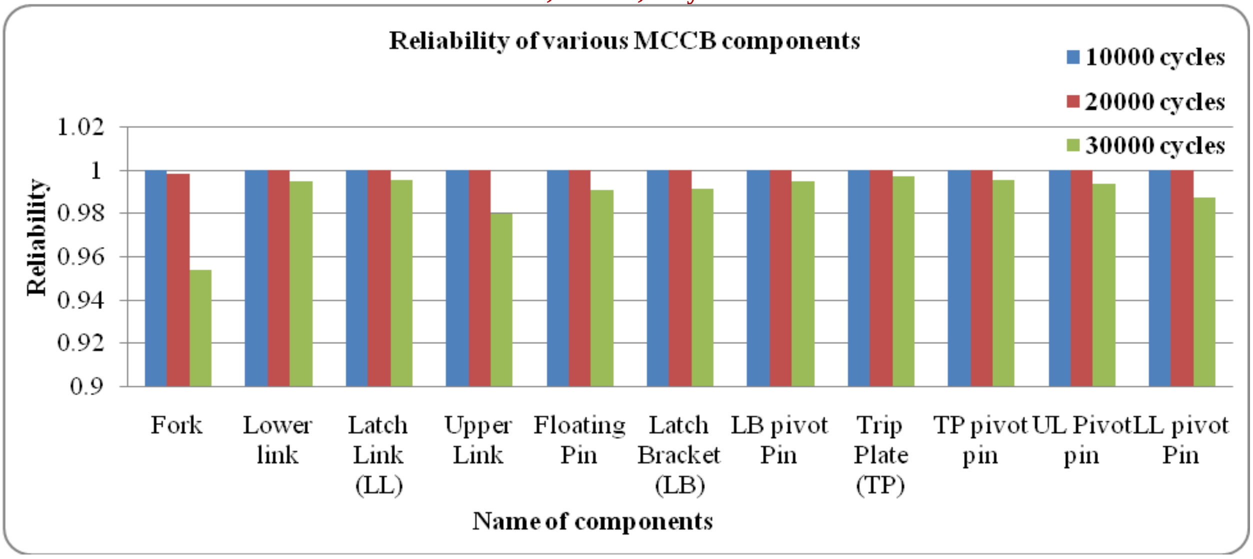

Fig. 5 Reliability representation of various components

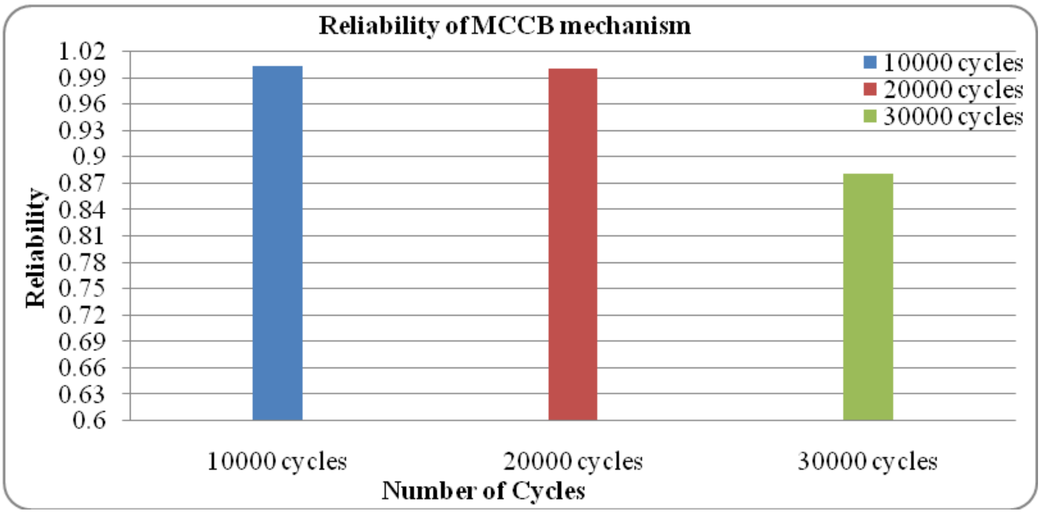

Fig. 6 Reliability representation of MCCB mechanism

VII. CONCLUSION

Reliability analysis of mechanical system in design and development stage is simpler based on SSI model with degradation analysis. It is conclude that after 30000cycles strength of MCCB mechanism component still greater than stress acting on component so there is less chance of component failure till 30000cycles. Reliability of MCCB mechanism for 30000cycles, 20000cycles and 10000cycles are 0.881033642, 1.0004329564, and 1.00275344 respectively. From reliability analysis of MCCB mechanism it is conclude that MCCB mechanism will survival for minimum 20000cycles without any failure introduced in mechanism. Decision making of MCCB mechanism for warranty period and maintenance strategy is simpler and accurate from reliability analysis.

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