TribologyandMaintenanceofMachinery-AReview

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Abstract*:*Thepresentpaperconsidersthetribologicalprincipleson themaintenanceofmachinerywhosethreeimportant areas are – Preventive, Condition Based and Proactive.Although breakdown is kept out of view, the morphology andanalysisoffailureprovideimportantinputsformaintenancestrategies. Condition based maintenance depends on three D's – Detection, Diagnosis and Decision. In many machinery systems,theproblemofpredictingtheremainingusefullife–theProactivepartoftheprogram,andevaluatingthecostbenefitsareof enormous importance. Here the authors endeavor to highlighthow the tribologist can significantly improve the maintenancepractice.

Keywords*: *Tribology, Preventive, Condition-based, Pro-activemaintenance.

I. INTRODUCTION

'TRIBOLOGY'awordofrecentoriginisastudyofFriction,Lubrication and Wear. The British Lubrication EngineeringWorking Group (1966) put it as "the science and technologyof interactive surfaces in relative motion and the particlesrelated there to". Whatever may be the genesis of the word,thequestionoffriction,lubrication,andwearwerereasonably understood by our fore fathers, even before thebeginning ofthe history.

Friction is helpful in many types of machinery for theiroperation;itisastonishingtolearnthataboutonethirdoftheglobalenergyproductioniswastefullydrainedoutbyfrictionalone. Frictionandweareinseparablyconnectedphenomenon and considering the fact that world economyrests on energy efficiency, tribology has gained a position ofsupremeimportance today.

Possibly no industrial unit can afford to throw away itsmachineriesi.e.capitalresources,unlesstheyhavebeenutilizedtotheirfullestextentoflifewithmaximumreliabilityand performance. Hence the concept of Maintenance arises.Many people had defined the term maintenance in differentrespect. But the following flowchart (fig: 1.1) defines themaintenanceinageneralizedview:

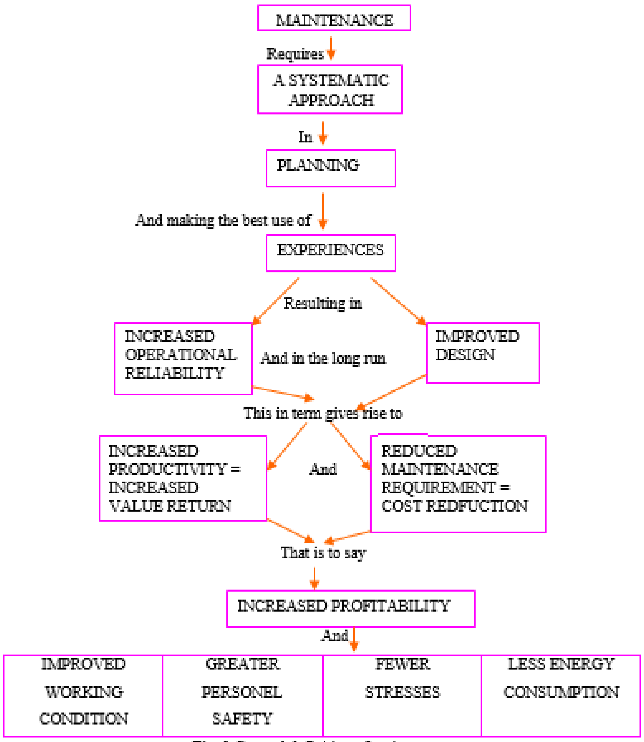

Fig: 1 General definition of maintenance

Inthispresentationthetribologicalaspectsandmaintenance practice are co related to ensure that criticallyoperating machinery fulfils their intended function and tocontinueforpre-expectedlifetime.

II. TRIBOLOGICALPRINCIPLESAPPLIEDTO MAINTENANCEPRACTICE:

A. Maintenancepractice–a review

PriortoWorldwarII,themaintenanceofmachinewasperformed onthebreakdownprinciple.Inthissortofpractice the machines were the machines were continuouslykept in service until it could not continue its normal functionany further, which means "**Don't fix it, until it is broken**".During this concept the human senses like eyes, ears, smell,touchandeventastewasconsideredduringobservationduringobservation.Butthiswouldleadtodisruptionofproductionplansasthetypeandthetypeofbreakdownareofrandom nature and may even cause loss of life. Meanwhiletheconceptpreventivemaintenancewasevolvedduringwhichtheequipmentwereregularlyinvestigatedonthedaily weekly, monthly or shutdown basis. During this, the faultyparts were get repaired/replaced, improving the life of theequipment.

Butthisconceptwasfurthermodifiedasitwasnottakencareofabnormalityandsuddenchangeoftheequipmentparameters. This background developed a new concept inmaintenancepracticewellknownascondition-basedmaintenanceinwhichabnormalityofmachineriesandchange-inequipmentparametersweretakencareofinadditiontopreventivemaintenance.Someindustryhadadopted the new concept in demand, proactive i.e. root causeanalysisforpredictingtheremainingfuturelifeofanyequipment.

All these concepts may be used by any industry alltogetherorindividualone.Thisistotallydependinguponthewholespectrumoftheindustryi.e.thetypeofbusinessinvolved, the type of machinery deployed and the workforceavailability–skilllevelandturnoverofstaff.Thesignificance of adopting these approaches is to find an answerforthequestionof"**failtofulfillitsfunction**",andwhatmaycausethat "**lossof life**"?

B. Tribology-itsprinciple:

Friction, Wear between mating surfaces, and Lubrication–these are three major areas of tribology. As the technology isdeveloped the modern machines are designed for "providingmore power", in a small size. As a result, very small areaavailable in the contact of mating surfaces to transmit therequisiteincreaseinloadathighspeeds.Athigherspeedstheinstability and the temperature rise are the main two threatsfor the continued smooth operation. Due to limitation forimprovingthepropertiesofthematerial(matingsurfacesandlubricant), friction and consequent wear will increase, with acorresponding rise in temperature and removal of surfacematerialleadingtoeitherseizureorinstabilityduetounacceptablewear.Toovercomethisdrawbackthelubrication theorywasdeveloped.

In the later 70's when there was a relative increase inthe cost of energy arising from the energy crisis the clearindicationwastoconserveenergyandrawmaterialsbyimproveddesignapplyingtribologicalprinciple.Butthattime very few industries were realized/aware the necessitiesorpossibilitiesforimprovementintheirpracticesbyapplying tribological principle. Even they are not sure todecide which machinery health monitoring techniques werebestsuitedfortheirpurpose.Nowindustrieshaverealizedthesafety as the highest priority, therefore more concentrationhad beengiventothemaintenance practice.

C. TribologyandMaintenance:

Now-a-daystheconcept-"**PreventionisBetterthanCure**"-is applied along with the outcomes of tribological research,for manufacturing components with improved design. Withthisapplicationamarkedchangeintheperformanceofmachineryisobserved.Throughoutthemajorareasofmaintenanceactivity,tribologicalprinciples(table:01)applied are–Preventive,Condition based andProactive.

Table:01

Maintenance activity	Tribological input	Decision
Preventive	Checks all the probable causes / parameters prone to failure at regular interval.	Replace /change the parameter/ causes to their pre-designed value.
Condition based	More attention to the parameters having highest priority towards failure.	Supplant / cause accordingly.
Proactive	Analyze the causes of failure at the root level.	Prediction of remaining wear life on the basis of root causes.

III. FAILUREANALYSIS:

The term '**Failure**' is widely used to indicate the loss ofability to perform specified function. To identify and isolatethe causes of failure an analysis is often carried out in threefunctionalareas–design,productionandend-useenvironment. The failure pattern, frequently described as thelifecyclefromcradletograve,commenceswithahighincidenceofinfantmortalityexhibitinghighfailureraterelatedtotribologicalcomponentssuchasweardebrisproduction rate, intensity of noise, etc. This is followed by aconstant or slowly increasing failure rate and finally by awearoutzone,wherecomponentreplacementbecomesessential.

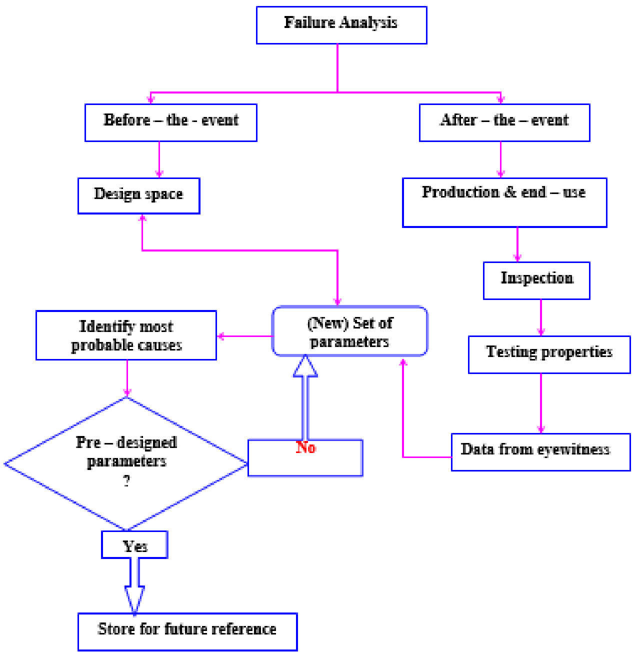

Fig 2: Flow Chart depicting Failure Analysis

Todeterminethemostprobablecausesoffailurethefollowing stepsmaybe followed:

a) Thoroughinspectionofthemachineryandfailedparts.
b) Studycarefullythechangesinmechanicalandchemicalpropertiesofthefailedpartsinthelaboratory.
c) Collecttherelevantdatafromeyewitnessandcompareitwiththedatarelatedtooperatingcondition.
d) Study all the parameters inthedesignspace.

e) Identifythemostprobablecausesandcompareitwiththep re-designedparameterenvelope.

f) If it violates, create a new set of parameters for thedesign space, otherwise store information for futurereference.

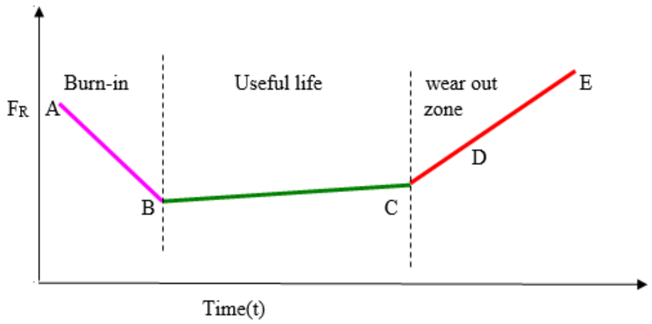

Fig.3: Life cycle of machinery on Log-Log scale

A – New or next repaired Machine.
B – Useful life begins.
C – First alarm (Indication towards failure).
D – Second alarm (repair).
E – Machine failure.

Table:02

	Significant Nature	Probable causes	Measures to be adopted
Burn-in	Decreasing failure rate	Welding flaws, cracks, defective parts, poor quality control, contamination, poor workmanship.	• Burn –in testing • Screening • Quality control • Acceptance testing
Useful life	Constant failure rate	Environment random loads, human error, chance events ('Acts of God')	• Redundancy • Excess strength
Wear out zone	Increasing failure rate	Fatigue, corrosion, aging, friction, cyclic loading	• De rating • Preventive maintenance • Parts replacement technology

Themathematicalrelationbetweenthefailurerateandtimeisgiven by,

$F_R=(\beta/\theta)x(t/\theta)^{\beta-1}$ for$\beta>0$, $\theta>0,t\geq0$

whereβ is a shape parameter, in the burn-in region $\beta<1$, intheusefullife $2\geq\beta\geq1$and

inthewear-outzone$\beta\geq2$

θisascaleparametertatinfluencesboth themeanand the spread, ordispersionof the distribution.

However,takingnaturallogarithm onbothsidesyields,$\ln(F_R)=(\beta-1)\ln(t)+(\beta-1)[\ln(\beta)-2\ln(\theta)]$

$\ln(F_R)=(\beta-1)\ln(t)+C$-------------------------(i)

whereCisafailureparameterwhichisafunctionof β andθ, in theburn-inregion$\beta<1$,in theusefullife2 $\geq\beta\geq1$ and

Reliability function $R(t) = \exp[-\int_0^{\infty}[(\beta/\theta) \times (t'/\theta)^{\beta-1}dt']$ $=\exp[-(t/\theta)^{\beta}]$

Probabilitydensityfunction$f(t)=-[dR(t)/dt]=\{(\beta/\theta)x(t/\theta)^{\beta-1}\}x\exp[-(t/\theta)^{\beta}]$

MeanTimeTofailure(MTTF)$=\int_0^{\infty}tf(t)dt=\theta\Gamma\{1+(1/\beta)\}$

$[MTTF=\int_0^{\infty}tf(t)dt=\int_0^{\infty}[\{(\beta/\theta)x(t/\theta)^{\beta-1}\}x\exp\{-(t/\theta)^{\beta}\}]tdt$

Let$y=(t/\theta)^{\beta}$,then$dy\{(\beta/\theta)x(t/\theta)^{\beta-1}\}dt$,

$MTTF=\int_0^{\infty}te^{-y}dy$,sincet= $\theta y^{1/\beta}$, we have

inthewear-outzone$\beta\geq2$.

$MTTF=\theta\int_0^{\infty}y^{1/\beta}e^{-y}dy$

$=\theta\Gamma\{1+(1/\beta)\}$ {since $\Gamma(x)=\int_0^{\infty}y^{x-1}e^{-y}dy\}]$

Forexample,acompressorexperiencesthefollowingfailurerate function:

$\ln(F_R)= -0.1.\ln(t)+C,\beta=0.9\&\theta=1000$ -----------------------(i)
$=C$
, $\beta=1\&\theta=1000$____(ii)
$= \ln(t)+ C$, $\beta=2\&\theta=1000$ ----------------------------(iii)

$MTTF=t_1+t_2+1000\Gamma\{1+(1/2)\}= t_1+t_2+886.23$ hrst_1+t_2canbe calculatedfromlog-logplot equation (i), (ii) and (iii) can be simplified by imposing thegiven conditions.

$\ln(F_R)= - 0.1\ln(t)+1.39$ ---------------------- (ia)
$=0$-- (iia)
$= \ln(t)-13.12$ --------------------------(iiia)

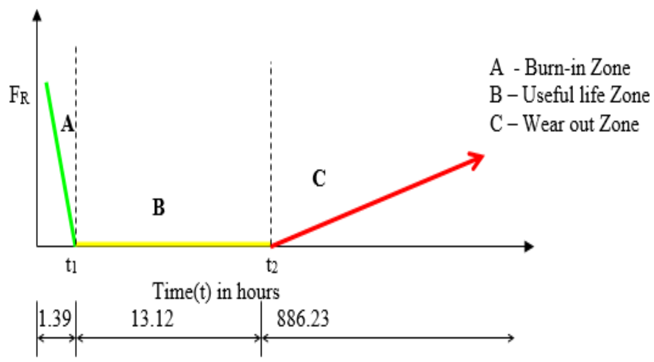

Fig 4: Life cycle of compressor

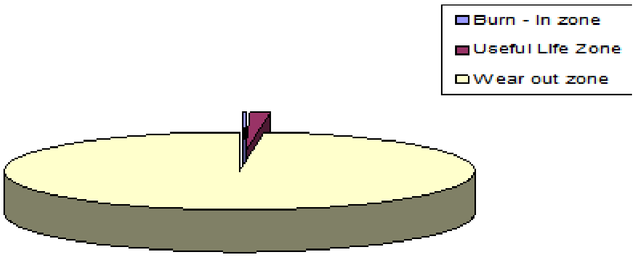

Fig 5: Percentage Life cycle of a compressor

A. Preventivemaintenance:

Itcanbetermedasplannedmaintenanceoftheequipmentconducted periodically to locate faulty condition and takepreventive actions to avoid or minimize chances of delay,thereby, this method ensures long and safe working of theequipmentwithoutanymishap.Asthepreventivemaintenanceisbasedonoverhaulingtime,previouslyexperienced and expected life of wearing components, theaction may often be taken before it is really necessary andreliability of the equipment is ignored. This technique doesnotguardagainstunexpecteddeteriorationbetweenoverhaul,as there is nomonitoringsystemis provided. Hence thedevelopmentofdifferentconceptinmaintenancesystemarises.

B. ConditionBasedMaintenance:

In condition-based maintenance the monitoring systemplays the most important role in detecting the condition ofmachine. Condition monitoring will provide the regular dataforassessingthemachineconditionaswellastoawarewhenprecautionswillhavetobetaken.Themeritsofcondition-based maintenanceare:

i) Increasingreliabilitybyreducingtheprobabilityofsudden/unexpectedfailure

ii) Increasing the time interval between consecutiveoverhauls

iii) Reducingun-necessaryreplacementofmachineparts

The most commonly used monitoring system (table:03)related totribologyis:

Table:03

Technique	Purpose
Vibration analysis	To check the dynamic instability due to lose fittings & misalignments
Thermography	Temperature surveillance technique to study mechanical & chemical properties
Wear debris analysis	To find mode of wear, debris size analysis, type of wear
Intensity of noise	To detect the abnormality in machines (by experienced maintenance personnel)
Lubricant analysis	To check the quality & quantity of the lubricant.

C. ProactiveMaintenance:

Itisacombinationofcondition-basedmaintenanceandthedata available from the previous failure. The raw data werecollected from monitoring system and compiling with thepreviousfailuredata,predictionoftheremaininglifeofa probability of failure before the next major overhaul. Mostcritical repairs get the highest priority during minor overhauland less critical repair is deferred to the major overhaul,reducingthe overall downtime.

IV. WEARDEBRISANALYSIS:

WeardebrisanalysiswasfirstdevelopedinU.KbymeansofMagnetic Debris Plug (MDP) in the lubricating systems. Butthemostsignificantdevelopmentwastheferrographytechnique.Bythistechniquethemorphologicalcharacteristicof the debris is identified and compared with the standardobservation charts. Debris analysis gives the idea of type ofwear that is occurred, by the worn surface and the size of thewearparticle.Italsoensuresaboutthemodeofwear(i.e.dueto rubbing, cutting, severe sliding or any other mechanicaloperations)from the sizeandsurfaceof thedebris.

For establishing a definite relationship between differentwear condition and their associated wear debris generally aprogrammedbasedatabaseisdeveloped.Regardingthisprocedure a large number of tests are performed on the samemachineunderdifferentoperatingconditionontheprobability basis, and a comprehensive wear particle databasewasacquired.Amonitoringtechniqueofdebrisanalysisisshowninfigure06.

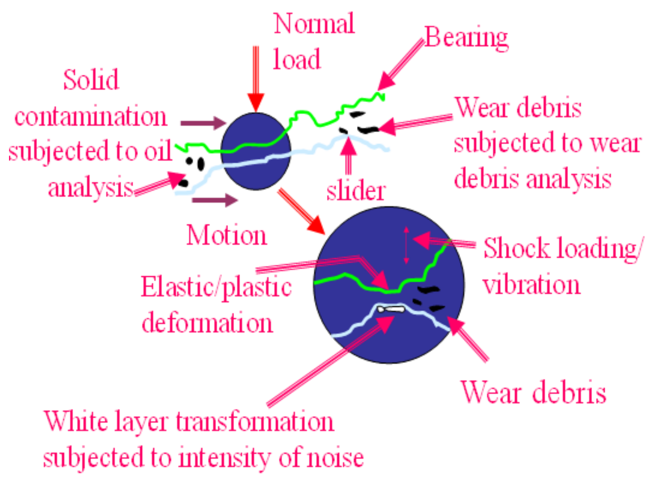

Fig. 6 Analysis of debris

V. CONCLUSION:

The effective maintenance of machinery lies primarily inapproximately communicating knowledge of its tribologicalbehavior and the practical consequences in relation to failureanalysis.ImplementationofthreeD's–Detection,Diagnosisand Decision in the field of maintenance of machinery mayhopefully ensure safe, reliable and efficient operations andhelp any industry to achieve profitable value return amongstcompetitive.

Finally,

1. Applicationoftribologicalprinciplesonmaintenanceofmachineryhelptopredicttheremainingusefullifeofthefailing machinery.

Bybalancingpreventive,condition-basedandpro-activemaintenancepracticesavailabilityofmachinery canbe improved.

Totalexpenditurecanbeminimizedbyreducingthesparepartstock.

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