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# AUTOMATED ANALYSIS OF WEAR PARTICLES THROUGH TRIBO ANALYSIS OF USED OIL FOR MACHINE CONDITION MONITORING

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## ABSTRACT
Wear particle generation in any tribological system becomes a result of various interrelated factors of the machinery. These particles generally formed due to surface interaction, which may be the valuable source of information on wear mechanism and its mode. Automated analysis may be able to obtain the qualitative information on the type of surface damages such as, fatigue, cutting, severe, rubbing etc., severity of loading, effect of temperature, quality of lubricant and so on. In the present work, optical microscope has been utilized with color CCD camera, which has mounted on it for acquisition of image purpose and lots of image processing has been done after periodic ferrographical testing. Some of the soft computing techniques have also been adopted in the present work for the diagnosis purpose of the present system.

**Keywords:** Digital image vision, Fractal dimension, Machine condition monitoring.

## 1. INTRODUCTION
In any mechanical equipment rotational part is quite important factor as it involves a lot disturbances or noise due to some machinery hazards and that is why the automatic detection, classification with prediction or prognosis of the failures has become a key role in maintenance engineering. Automatic monitoring offers the promise of substantially reducing the cost of repair and replacement of defective parts and may even result in saving the lives of the equipments.

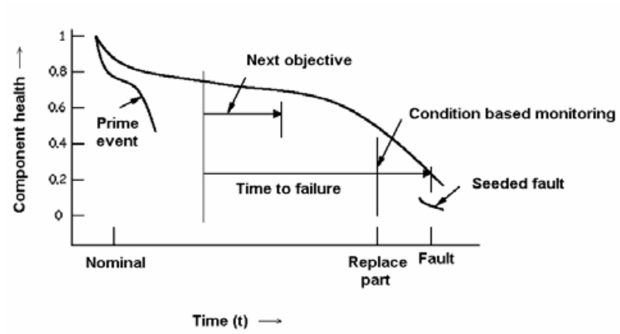


Fig 1. Machine health rate

Wear particle examination by image vision system is quite a big task in condition monitoring technique, which requires skilled and experienced personnel so that the costly failures can be optimized. Condition based monitoring is having the monitoring techniques allied with the diagnosis i.e. failure identification of the machinery and accordingly the prognosis i.e. prediction of remaining life of the equipment can be detected easily.

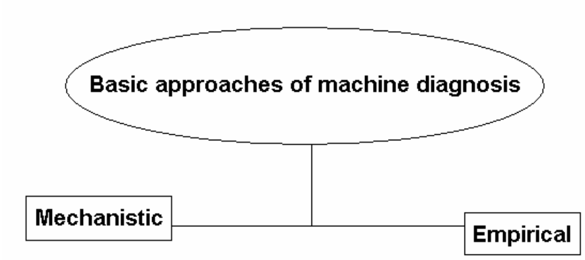


Fig 2. Approaches of machine prognosis

In Fig.2, the basic approaches have been shown and among them empirical based diagnosis involves artificial intelligence. In the present work, the image of various wear particles have been acquired through CCD acquisition and with the help of image processing the mode of wear has been detected and finally maintenance action can be taken.

## 2. CONDITION MONITORING
Condition monitoring of any system gives the white or a grey box system where, it can restrict the variety of possible observable system states. Sometime, the human error may affect the observation of the states of the machinery so that a person does not recognize the system state or reports the observed system state subjectively. Fig.3 shows different techniques in machine condition monitoring, where all types of constraints can be accepted so that a proper strategy can be taken care of.

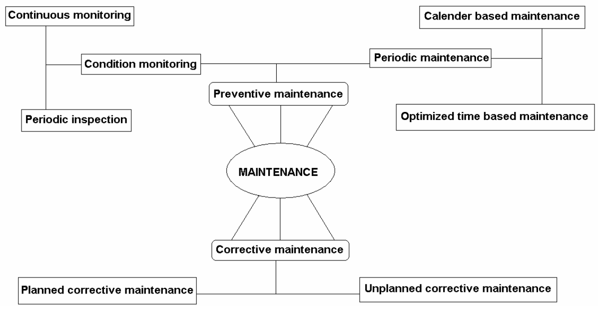


Fig 3. Maintenance actions in integrative way

Generally, there are some technical steps involved in doing a proper maintenance action. The entire maintenance policy is segmented into several parts such as,

- Repair of the equipment
  - ✓ Breakdown stage
  - ✓ Scheduled maintenance stage
  - ✓ Reconditioning stage
  - ✓ Up gradation of service stage
  - ✓ Reverse engineering stage
  - ✓ Alignment or balancing stage
  - ✓ On or off-side service stage
- Oil analysis
  - ✓ In service condition monitoring of the lubricant
  - ✓ *Wear debris analysis*
  - ✓ Mechanical condition monitoring wear parts
  - ✓ Monitoring the lubricant viscosity
  - ✓ Measurement of concentration of contaminants
- Vibration analysis
  - ✓ On-site diagnostic assessment
  - ✓ Communication support
  - ✓ Preventive maintenance program support
  - ✓ Turnkey preventive maintenance services
  - ✓ System design
- Troubleshooting
  - ✓ Engineering assistance in identification and resolution of the operational problems
  - ✓ Automated system analysis
  - ✓ Component analysis
  - ✓ Sound detection
  - ✓ Vibration analysis
  - ✓ Failure analysis
- Failure analysis
  - ✓ Detection of root cause of failure (s)
  - ✓ Evaluation of entire system
  - ✓ Permanent corrective actions
  - ✓ Operational load
  - ✓ Component design
  - ✓ Maintenance practices
  - ✓ Analysis of failed component (s)

## 3. WEAR PARTICLE ANALYSIS

Wear can take place in many forms depending upon the nature and geometry of the interacting surfaces, the environment in which they interact and the load. There are two main types of wear i.e. *mechanical* and *chemical*. Mechanical wear involves processes, which is associated with the friction, abrasion, impact and fatigue. Whereas, chemical wear arises from an attack of the surface by reactive compounds and the subsequent removal of the products of reaction by mechanical action. The most important and difficult task in wear mechanism is the detection and measurement of wear during the operating condition of machines. So, wear is basically a surface degradation.

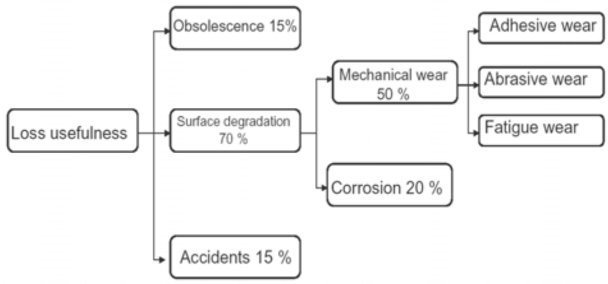


Fig 4. Wear rate in any mechanical system

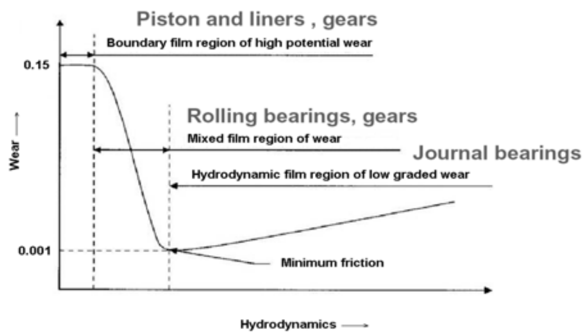


Fig 5. Wear for different components

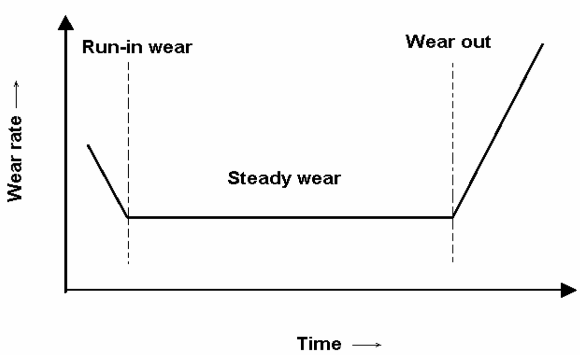


Fig 6. Wear characteristics

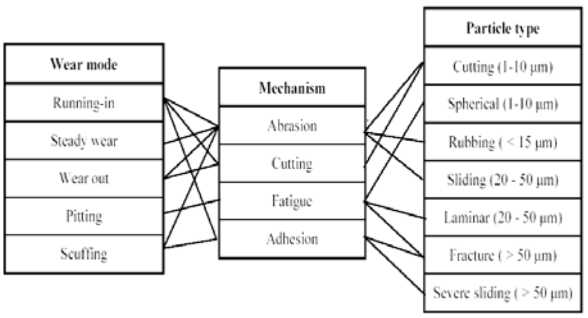


Fig 7. Various wear mode

## 4. IMAGE VISION TECHNIQUE

Image data represents the physical quantities such as chromaticity and luminance. Chromaticity is the color quality of light defined by its wavelength, whereas luminance is the amount of light. The color image information can be acquired with the help of its hue, saturation and lightness. Apart from this characteristics there are some several properties involve in determining the type of the images i.e. its saturation, lightness, contrast etc. Among them, saturation is the degree to which a color is undiluted with respect to white light, lightness is the perceived intensity of the reflecting object and contrast is the range from the darkest region to the lightest region of the image. If $I_{max}$ = maximum intensity of the region and $I_{min}$ = minimum intensity of the region described, then contrast can be interpreted as,

$$\text{Contrast} = \frac{I_{\max} - I_{\min}}{I_{\min} + I_{\min}} \qquad (1)$$

Similarly, the color space for any image can be represented by RGB (red, green and blue) combination,

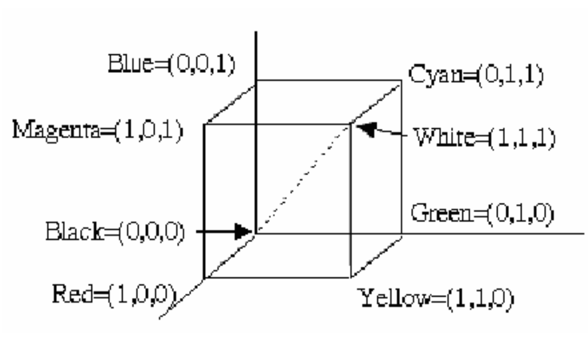


Fig 8. RGB color distribution

The relationship between the RGB and HSI can be represented as,

$$I = \frac{1}{3}(R + G + B) \qquad (2)$$

$$S = I - \frac{3}{R + G + B}[\min.(R, G, B)] \qquad (3)$$

$$H = \cos^{-1}\left[\frac{\frac{1}{2}(2R - G - B)}{\sqrt{(R-G)^2 + (R-B)(G-B)}}\right] \qquad (4)$$

These are the most common methodologies in image processing and in the present work they have been utilized. Apart from the mathematical interpretation, some other techniques like filtering of image, masking of image, edge detection, histogram equalization etc. has also been covered in the present work.

## 5. FRACTAL MATHEMATICS

The term fractal first innovated by Mandelbrot with having some typical characteristics such as,

- fractal can have all details related to an object
- it is approximately self-similar geometrically
- it follows a particular algorithm

Hence, fractal can be defined as,

$$D = \lim_{\varepsilon \to 0} \frac{\ln N}{\ln(\frac{1}{\varepsilon})} \qquad (5)$$

where, D = fractal dimension
N = total no. of pixels in an object
ε = no. of pixel covered in any image

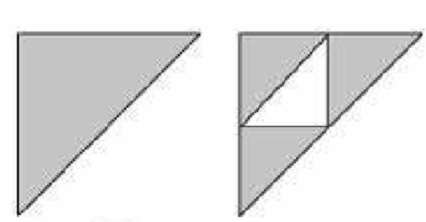

Fig 9. Sierpinski triangle

Suppose, in Fig.9, N = 3 and ε = 1/2, then from eq. (5),

$$D = \lim_{\varepsilon \to 0} \frac{\ln(3)}{\ln(2)}$$

and finally D = 1.584. In this way, the fractal can be determined for any shape. The present work tries to investigate the fractal dimension of irregular shaped object after using the image processing techniques. There are some fractal based algorithms which have been utilized in the present work, amongst them EXACT, FAENA and FAST methods are quite reliable.

### 5.1 EXACT method

In the EXACT method, an arbitrary pixel has chosen on the boundary of a particle as a starting point and a pair of dividers has set to an initial distance, i.e., the step length 'ε'. Another point on the boundary has then found at an exact distance 'ε' from the starting point. This second pivot point can be used to calculate the location of the third pivot point at a distance and so on. This procedure has been repeated until some closure length occurs from the n$^{th}$ pivot point back to the starting point. In each iteration, the incremental step length has been considered as,

$$steplength = steplength + 0.01^{10}(numberloops \times 0.03)$$

…………… (6)

### 5.2 FAST method

This method is just like walk around the boundary of a place. In this case, a straight line and finally their Euclidian distance to be calculated connect starting and ending step size.

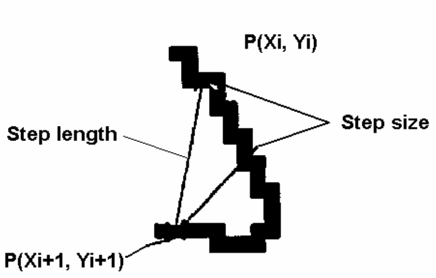


Fig 10. FAST method

$$steplength = steplength + trunc[10^{10}(numberloops \times 0.015)]$$

(7)

### 6. CASE STUDY

The present work deals with the ferrographical technique of used oil analysis by CCD acquisition incorporated with the microscope. The used oil sample has been collected from a reputed nationalized company nearby Kolkata (India) and it has been checked ferrographically about its severity. Accordingly the ferrograms have been prepared and those have been utilized in CCD camera for image processing techniques. Some of the images with their fractal dimension values and image processing have been given in the following figures and tables. Table 1 shows the wear mode and its fractal values with various steps involved in image processing. In this image Prewitt testing for edge detection, Canny testing for edge detection, Sobel testing for edge detection, adjustment of image intensity level, histogram of the original image data after adjusting the intensity level, estimation of the background intensity at grey level scale, thresholding the complementary image to show the small structure of the image, masking of the image etc. operation have been performed carefully. In similar way other modes of wear has also been detected by image processing techniques.

### 7. DISCUSSION AND CONCLUSIONS

Wear occurs whenever one surface interacts another surface and depending upon the no. of particles generated between their surfaces severity can be judged. Generally, the number of bigger particles increases when wear is severe.

If, $D_L$ = Number of larger particles
$D_S$ = Number of smaller particles
$D_L + D_S$ = Concentration of solution
$D_L - D_S$ = Size distribution
Then, Severity index (S.I.) can be represented as,

$$S.I. = (D_L + D_S)(D_L - D_S) = (D_L^2 - D_S^2) \quad (8)$$

The rate of S.I. can be detected by,

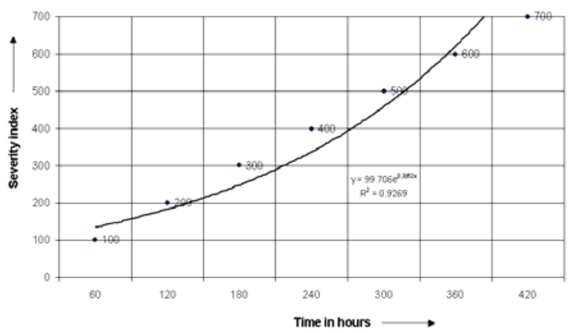


Fig 11. Rate of severity index

Present study involved in industrial used oil from where the values of geometrical parameter have been found out successfully but amongst them fractal dimension has been highlighted strongly. At the same time a lot of image processing techniques have been performed so that the automated data can be utilized properly for making a proper maintenance strategy. In the present work as some of the wear mode have been found like, severe wear, fatigue chunk, laminar wear etc. therefore, the machine overhauling can be done for the existing setup for increasing the life of the machinery.

### 8. REFERENCES


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Table 1: Automated analysis of images (severe wear)

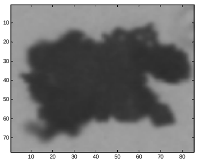
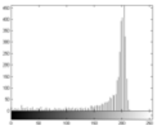
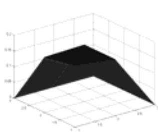
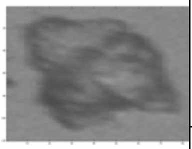
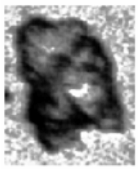
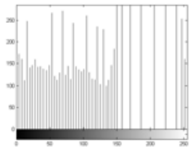
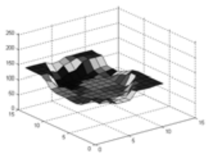
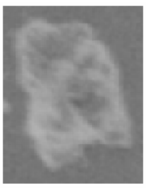
| Original image | Processed image | | | | |
|---|---|---|---|---|---|
|  |  |  |  |  |  |
| |  |  |   |  | Fractal dimension = 1.042<br><br>Mode of wear = Severe wear |

Table 2: Automated analysis of images (fatigue wear)

| Original image | Processed image | | | | |
|---|---|---|---|---|---|
|  |  |  |  |  |  |
| |  |  |  |   | Fractal dimension = 1.0182<br><br>Mode of wear = Fatigue wear |