STUDY OF WEAR IN PISTON RING OF A VEHICLE ENGINE USING THIN LAYER ACTIVATION TECHNIQUE

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Abstract: Thin Layer Activation (TLA) technique was used to investigate piston ring wear of a six cylinders vehicle engine at various engine speeds and load conditions. The activated ring was installed in cylinder # 5 of the engine at middle position on the piston (compression ring). Monitoring was carried out on-line (externally on the engine block) using 'Thin Layer Difference Method'. The calibration curve of the activity profile was prepared with the help of activation parameters determined at the time of ring activation in particle accelerator. The results show that the piston ring wear varies from 0.309 micron/hour to 0.404 micron/hour at given engine speed and load conditions.

1. INTRODUCTION

Wear and Erosion are processes that remove material from surfaces of engineering components and plant materials. Eventually, these can cause maintenance problems, life reduction of plant components and financial loss of plant capital. These processes significantly affect the efficiency and reliability of machine parts and industrial equipment. A reliable and on-line measure of wear and erosion can result in substantial savings in time and money during the development of machine components and lubricants. Moreover, on-line monitoring may be used to minimize costly downtime and unscheduled interruptions during a component's lifetime. Various nuclear methods have been reported for wear measurement in automotive industry and tribology [1, 2]. By providing real-time information on the status of critical components, the Thin Layer Activation (TLA) technique provides a considerable insight, which can help to optimize maintenance programs and get a better knowledge of the useful life of a component.

TLA technique is an application of charged particle activation in which a beam of charged particles is directed into the surface of a target material. As the particles penetrate into the surface, they slow down due to collisions, principally with the electrons of the target atoms. While the energy of the particles remain above the cross-section threshold, some of them undergo nuclear reactions with target nuclei. If the product nuclei of these reactions are radioactive, then the target surface is labeled with a depth profile of radioactivity. About 1 in 10^{10} of the target nuclei can be expected to change, and the metallurgical properties of the surface are left unchanged [3].

If the activated surface is exposed to some process that attacks it, then it is possible to monitor the surface metal loss by simply measuring the proportion of radioactivity left [4, 5]. Unlike other techniques, the strength of TLA is that it has a direct correspondence with surface loss, be it by wear, erosion or corrosion. Alternatively, if a filter collects the removed metal, the buildup of radioactivity at this collection point can also be used to monitor surface loss. In either case, it is imperative that the removed surface is transported away from the activated area. TLA technology reduces significantly the number and duration of tests and thereby saves considerable amount of time and money on recurrent studies and inspection procedures. Therefore, it is an economical and extremely efficient way of monitoring wear and corrosion in any industrial application, provided that the wear particles are removed from the labeled zone.

2. METHODOLOGY

The Methodology of the technique consists of labeling of component with radioisotope (activation), calibration, installation of piston ring in the vehicle engine and monitoring of wear. The piston ring was activated by rotating the ring, in air, before a collimated beam of 12 MeV protons. This provided a uniform band of radioactivity that was restricted to the outer ring surface. The depth of activation was controlled with the energy of incident proton beam. The ion beam intensity and the activation duration precisely control the quantity (the activity level) of isotopes created [6]. The following nuclear reaction was used to label the piston ring with radioactive material.

$$^{1}p_{1} + ^{56}Fe_{26} \longrightarrow ^{56}Co_{27} + ^{1}n_{0} \quad -5.351 \text{ MeV}$$

The product nucleus ^{56}Co emits γ-rays of energy 847 keV and it decays with a half-life of 78.8 days. The gamma energy of ^{56}Co is sufficient enough to penetrate out of the engine block that enables external monitoring during the operation of the engine. The necessary constants required for the calibration and subsequent computation of wear depth, were also determined during ring activation.

Piston ring was installed in vehicle engine which, in turn, was fixed on a test bench. Residual method, also known as Thin Layer Difference Method, (Fig. 1) was used to monitor the wear of piston ring [4]. The engine was operated for the following stable engine operating parameters as given in Table 1:

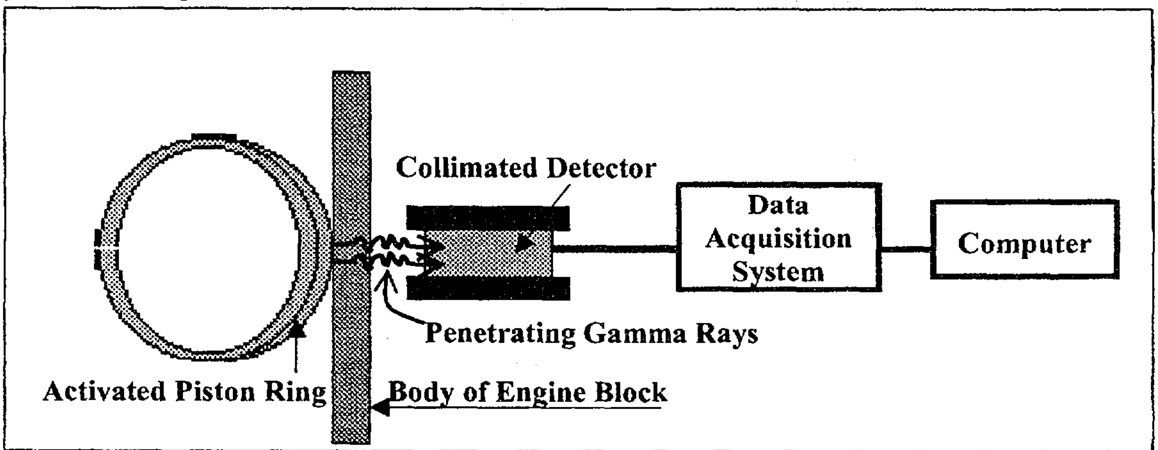

Fig. 1. Schematic of wear monitoring set-up using thin layer difference method

Table 1. Parameters for engine operation during piston ring wear test

Experiment No.	RPM	Load	Operation Time	REMARKS
EXP #1	~350	No Load	13 minutes	Motoring*
EXP #2	~650	No Load	130 minutes	Idling (with fuel ignition)
Engine Oil Changed				
EXP #2	1000	12 N.m	38 minutes	Engine warm up
EXP #2	2000	104 N.m	100 minutes	Stable engine operation
EXP #3	2500	100 N.m	210 minutes	Stable engine operation
EXP #4	2500	150 N.m	130 minutes	Stable engine operation

* The engine was run externally with electric motor

3. RESULTS

3.1. Data Analysis

The original data was collected at 10 seconds counting interval. However, to reduce the statistical error, the data was integrated to counting interval of two minutes. The data of each measurement was processed and corrected to take into account the background radiation and natural radioactive decay of radioisotope ^{56}Co.

3.2. % Activity Lost

The corrected data (Counts/2 minutes) was plotted against engine operation time (Fig. 4). The regression line of the data gives an equation that governs the rate of activity lost. The Y-intercept of this line gives mean initial value of the activity for respective engine operation. This initial value of activity (Y-intercept) is used to calculate the % activity lost at each counting interval of time as follows:

$$\textbf{\% Activity Lost} = \frac{\textbf{(Initial Activity - Activity measured at time 't')}}{\textbf{(Initial Activity)}} \times 100 \quad \text{------ (1)}$$

3.3. Calibration

Various calibration techniques have been described in literature [7, 8]. The calibration curve (Fig. 2) of the activated piston ring gives the relationship between **Micron Lost** (Wear) and **% Activity Left**. This calibration curve was calculated following experiments using stacks of iron foils to measure reaction yields. This curve is governed by the following empirical equation:

$$\textbf{\% Activity Left} = 100(1 + d(\alpha + d(\beta + \gamma d))) \quad \text{---------------------------- (2)}$$

Where 'd' is depth of surface removed. α, β & γ are constants and are determined from the activation parameters while the piston ring is activated by proton beam in the particle accelerator [6]. The values of α, β and γ are **-1.3053x10^{-2}**, **3.4334x10^{-5}** and **6.2698x10^{-8}** respectively. The % Activity Lost is plotted against Micron Lost to obtain the final calibration curve. This calibration curve is shown in Fig. 3.

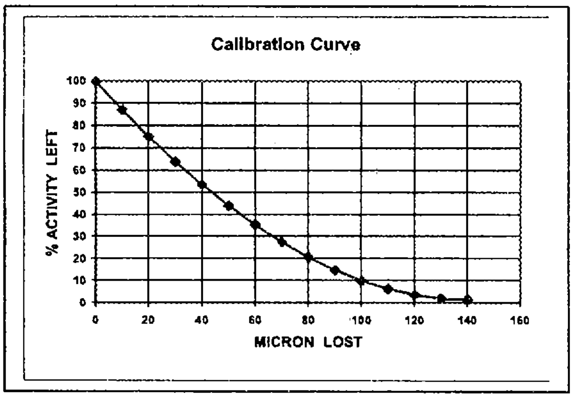

Fig. 2. Calibration curve (activity left-vs-surface lost;

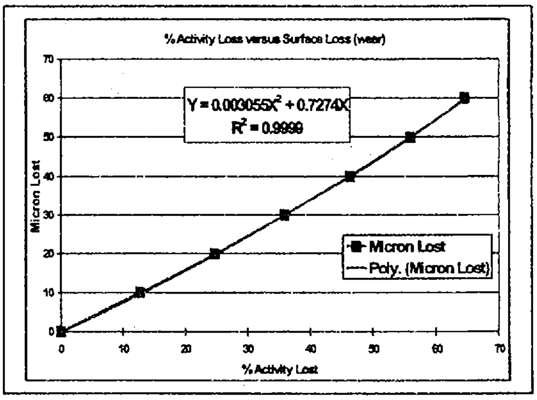

Fig. 3. Calibration curve (surface lost-vs-activity lost

The regression line equation of calibration curve is given below:

$$Y = 0.003055\ X^2 + 0.7274\ X \qquad [R^2 = 0.9999] \quad \text{-----------------} \quad (3)$$

Where 'Y' is Micron Lost and 'X' is the '% Activity Lost'. The value of R^2 shows a very good fit of regression line. The '% Activity Lost' is calculated for each interval of activity measurement. Substituting the values of '% Activity Lost' in equation (3), one can calculate the wear in 'Micron Lost' for each measuring interval. When this data is plotted against engine operation time, we have a relationship between wear and operation time. (Fig. 5, 6, & 7). The regression line of this plot (Micron Lost – versus- Operation Time in minutes) gives us the 'Wear Rate' in microns per minute.

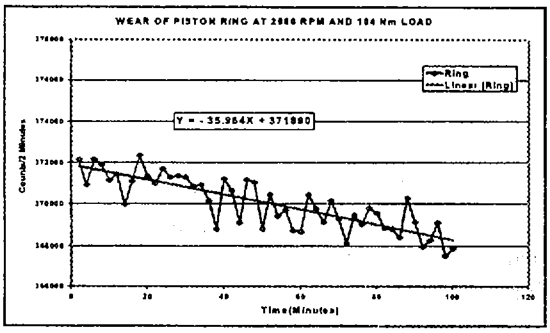

Fig. 4. Piston ring activity vs-time at 2000 RPM and 104 N.m Load

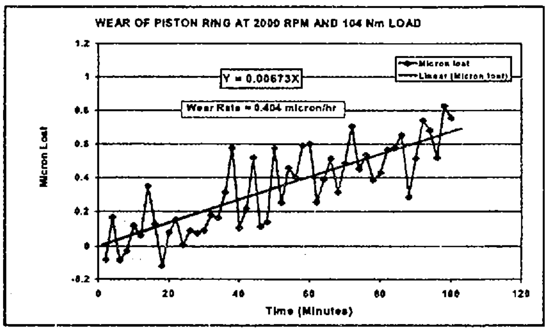

Fig. 5. Piston ring wear at 2000 RPM and 104 N.m Load

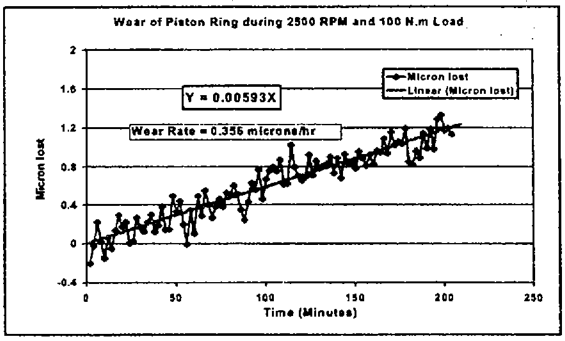

Fig. 6. Piston ring wear at 2500 RPM and 100 N.m Load

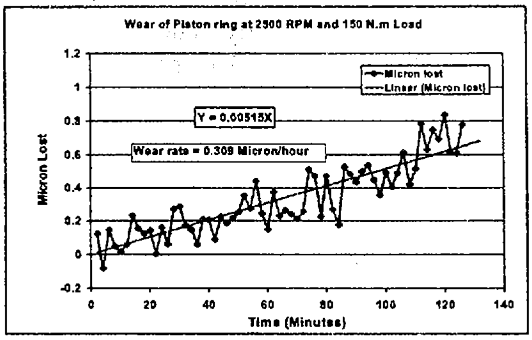

Fig. 7. Piston ring wear at 2500 RPM and 150 N.m Load

4. SUMMARY

The summary of the results is given in the following table:

Table 2. Wear rates of piston ring at various operating parameters

Sr. No.	Engine Speed (RPM)	Engine Load (N.m)	Operation Time (Minutes)	Wear Rate (Micron/Hour)	Remarks
1.	2000	104	100	0.404	Water Temp.(max): 70 °C Oil Temp. (max): 110 °C Oil Pressure (min): 24 psi
2.	2500	100	210	0.356	Water Temp. (max): 65 °C Oil Temp. (max): 17 °C Oil Pressure (min): 20 psi
3.	2500	150	150	0.309	Water Temp. (max): 75 °C Oil Temp. (max): 125 °C Oil Pressure (min): 15 psi

CONCLUSIONS

The present study has demonstrated that TLA Technique can be used effectively to monitor wear of engine parts under different operational conditions. The monitoring can be carried out on-line by portable radiation measuring system without hindering the operation of the engine. It is a very efficient and sensitive method to study the wear in the range of surface loss from less than a micron to more than 200 microns if wear rates are high. Although this study was confined to wear of piston ring, the technique can be extended to other engine parts like cylinder liner, bearings, gears cams, tappets, valve guides, valve seats and fuel injectors, etc. It can also be used for evaluation of lubricants and in many other engineering applications and industries where wear, erosion and corrosion processes are significant.

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