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Research Paper

Monitoring through T^2 Hotelling of cylinder lubrication process of marine diesel engine

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HIGHLIGHTS

- Process monitoring of Marine diesel engine cylinder lubrication.
- Detection of signals in the process, with a new data entry.
- Identification of process variables signaling that originated.

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ABSTRACT

Frequently, it can be complex to identify when a process, has a deviation from its normal working conditions, when the process variables are individually monitored. This paper responds to that need.

The cylinder lubrication process, of a 2T marine diesel engine, was monitored throughout multivariate control charts, for specific ship operation conditions; the historical data set in control the optimal working process was made and with a new entry of sample n = 23, observations out of statistical control were detected using Hotelling's T^2 control charts. The variables that generated the signals in the process were identified through the MYT decomposition technique. This technique could complement and not supplement the systems which monitor the independent variables and have a general vision of the behavior of the complete process.

1. Introduction

The monitoring of the equipment has reached such dimension, in which the manufacturing brands have developed very potent tools for data acquirement, which has derived in a growing process of computerization and monitoring, this allows the registration of frequencies with millisecond precision of a large quantity of variables in real time [1].

Monitoring redundant variables unnecessarily other than increasing measurement costs [2] can also derive in mistaken actions by the user, due to the difficulty in the interpretation of a large quantity of monitored signals at once, decreasing the efficiency of the process.

The challenge that process monitoring now faces is how to manage the large amount of correlated information which can be registered [1], reducing the number of monitored variables without losing process information, it is a way of optimizing the process, maximizing its efficiency, additionally to reduce the costs of measurement.

Within the monitoring techniques of processes, we can find computational techniques, and statistical techniques. The computational techniques, such as, fuzzy logic [3,4], genetic algorithms [5] and Artificial Neural Networks (ANN) [6,7] have been used in the monitoring of different industrial processes; i.e., means of ANN the energetic efficiency with reduction of HFO consumption was improved.

Monitoring using statistical techniques is carried out using control charts. The contributions to this field have been made through graphics Shewhart $\overline{X}$-S for univariate processes or the Hotelling's T^2 control chart, for multivariable processes [8]; in this issue, for monitoring the rectification process of inside diameter of a steel cylinder, Shewhart X-S control charts were used for three measurements performed in sections of a cylinder, analyzing them separately; further a multivariate Hotelling's T^2 control chart was used to monitor three measurements simultaneously. With both the results obtained were similar. However, the Shewhart control chart was easier to use and simpler to interpret by operators.

For that, these techniques are combined with others to try to detect the origin of the problem like the MYT (Mason, Young and Tracy) signal decomposition applied to food industry [9], the Hotelling's T^2 statistical was implemented in combination with

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the technique MYT, concluding that the multivariable control T^2, showed efficiency for detecting possible changes in the process and the statistic decomposition, facilitated the diagnosis of the changes in the process which originated the problem.

Using principal component analysis (PCA), in the metal industry [10], two techniques for monitoring and control of a multivariate normal process was proposed, control chart of Hotelling's T^2 and control chart of principal components analysis (PCA).

The control chart of Hotelling's T^2 detected that the process was out of rank but didn't identify the variables which were out of rank neither the possible trends that might be in the process variables; but the control chart of principal components, detected that the process was out of rank and also showed the trend of the process went to out of rank.

In the maritime naval sector, the machinery condition of vessel through satellite with PCA [11] was monitored using the algorithm to compress with sufficient accuracy the large amount of data that was collected on board and then sent them via satellite in a cheaper and faster way than traditionally.

D. Garcia-Alvarez and M.J. Fuente [12] studied the comparative between different methods for detection of faults based on PCA, applied on a laboratory plant, analyzing various parameters; Four of these parameters evaluated the method quantitatively: number of false alarms (ET1), average computing time in seconds to process a sample (TC), number of samples that were analyzed from that failure occurred until this was detected (RT) and minimum size of detected faults (FMD). On the other hand they studied two qualitative parameters: multiple fault detection (DMF) and adaptation to changes in the mode of operation (ACM).

The methods used were: PCA (Principal Components Analysis), APCA (Adaptative PCA), MSPCA (Multi-scale PCA), EWPCA (Exponentially Weighted PCA), PCAEA (PCA using External Analysis), PCANLEA (PCA using non-linear external analysis) y NLPCA (Non-linear PCA). The results are listed in Table 1.

After analyzing the results of Table 1, they concluded the following for each analyzed parameter. For the first parameter ET1, all methods reduced the number of alarms with respect to monitoring with PCA, but only the EWPCA and NLPCA methods eliminated false alarms; for TC, the EWPCA, PCANLEA y NLPCA showed computation times significantly higher and the other methods showed calculation times similar to PCA; for RT, all methods except EWPCA and PCAEA detected failure instantly. The restriction of failure detection was 10 consecutive alarms that for the period of sampling in this case was a second, this mean that the minimum detection delay was 10 s; for DMF, only the methods APCA and EWPCA were capable of detect a new failure thanks to its capacity Adaptive; for ACM, no method got to clearly differentiate between changes in the modes of operation and failure; and for FMD, all linear PCA modifications reduced this parameter. However, neural networks based increased considerably this parameter, probably due to its capacity of generalization.

Finally, the company Kongsberg A.S., with a cylinder liner monitoring system [13] monitors the piston running performance by measuring the temperature of the upper part of the cylinder liners in large 2T marine Diesel engines produced by friction between the piston rings and the cylinder liner.

When the measured variable exceeds the set limit alarm, regardless of the condition, it acts directly to the cylinder lubrication units in order to temporarily increase the cylinder lubrication.

In our study, we implemented multivariate monitoring of the cylinder lubrication process of a 2T marine diesel engine running, installed on a tanker ship, through Hotelling's T^2 control charts, for some specific working conditions.

Further, the variables that caused the out of rank state with respect to the normal operation of the ship were identified, through decomposition MYT.

The main difference with current literature is in the usage of this type of monitoring in the main engine of a ship in seagoing conditions.

Table 1
Comparative study.

	ET1 (%)	TC	RT	DMF	ACM	FMD (%)
PCA	4.62	8.03E−05	10	NO	NO	10
APCA	2.90	4.26E−04	10	SI	NO	5
MSPCA	2.82	1.81E−04	10	NO	NO	3
EWPCA	0	2.90E−03	12	SI	NO	3
PCAEA	2.92	9.27E−05	12	NO	NO	2
PCANLEA	2.83	2.70E−03	10	NO	NO	18
NLPCA	0.00	3.40E−03	10	NO	NO	19

2. Material and methods

2.1. The engine and its use

The aim of our study was to monitor the variables of a cylinder lubrication process of a 2T Marine diesel engine, which is frequently installed in tank ship and bulkarriers as the main engine. The basic technical details of engine are listed in Table 2.

The engine was installed on a Suez Max Crude Carrier with characteristics, listed in Table 3. This ship which sails, normally, carries out regular voyages, between Western Africa, and Northern Europe where he is unloaded.

The MAN B&W Alpha cylinder lubrication system is designed to supply cylinder oil intermittently and is independent of the other engine lubrication circuits (Crankshaft, camshaft, turbocharger...) [14]. The cylinder lubricating oil is pumped from the cylinder oil storage tank to the service tank. Cylinder lubricating oil is fed to the Alpha Cylinder Lubrication system by gravity about 3 m above main engine. The oil fed to the injectors responsible for injecting oil into the cylinders, is pressurized by means of the Alpha Lubricator which is placed on the HCU (Hydraulic Cylinder Unit) and equipped with small multi-piston pumps, this system is shown in Fig. 1.

Table 2
Technical details of engine studied.

Manufacturer	MAN B&W
Type	6S70ME-C8
Cycle	Low-speed 2 stroke
Nominal speed	91 r.p.m.
Rate power	19,620 KW
Number of cylinders	6
Stroke	2800 mm
Bore	700 mm

Table 3
Ship's specifications.

Name of ship	No available
Shipyard build	No available
Build year	2012
Type of ship	Crude oil tank
Class	Suez max
Length overall	274.20 m
Breadth extreme	48.04 m
Draught	17 m
Gross tonnage	81.187 Tons
Net tonnage	51.148 Tons
Summer DWT	159.179 Tons