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Computerized Condition Monitoring of a Diesel Engine Through Air Inlet Filter Analysis

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Abstract: The diesel engine consists of several components which enhance its proactive monitoring. One of these components is the turbocharger unit (compressor and turbine). It was found from this research that the effective and efficient performance of the unit depends mainly on the effectiveness of the air intake filter. The test engine used was an MTU 12V 396 TC 32 diesel engine. This research used computerized condition monitoring to avert failure, unplanned downtime and schedule maintenance, thus increasing the useful life of the engine. Component modeling was adopted as the best means of actualizing this aim. It was carried out for the air intake filter. A software code named “Top A” written in qbasic programming language was developed. The data obtained showed that the intake air differential pressure across the filter decreased at the range of 0.5 bar. The results revealed that the model developed is capable of predicting any blockage the air intake filter may experience. It was found that the measured pressure drop across the filter remained at 0.85 bar for a long time. This means that the performance of the filter was optimum at this pressure. Condition based maintenance philosophy is therefore recommended to be used to increase its reliability and flexibilityof the entire engine.

Key words: Turbocharger unit, air inlet/intake filter, downtime, computerized condition monitoring, maintenance, Nigeria

INTRODUCTION

With the increased use of diesel engines for power generation, there is every need to enunciate a proactive CM technology to be associated with the state of health of a component of the engine. In Lilly (1984) and Ogbonnaya (1998), it was shown that such a method is feasible.

To further actualize this method, a proactive computerized method of monitoring the health of the AMF through its blockage was used under the premuse of component modeling. The use of component modeling is already an established technique in CM. However, the importance of filter analysis into the method is novelle. Hence, this study goes a step further to show that for component modeling in plant, system or even sub-system should be neglected.

Air intake systems are usually one of two types: wet or dry. Figure 1 shows a cut-away view of a wet filter system. In this type, air is sucked through a housing that holds a bath of oil such that the dirt in the air is removed by the oil in the filter. The air then flows through a screen-type material to ensure that any entrained oil is removed from the air.

While in a dry filter system, paper, cloth or a metal screen material is used to catch and trap dirt before it enters the engine. A good air intake system is usually designed to take in fresh air from as far away from the engine as practicable. This is because it provides the engine with a supply of air that has not been heated by the engine’s own waste heat.

Workability of air intake system: Air intake systems are usually one of the two types, wet or dry. Figure 1 shows a wet filter intake system. In this type, air is sucked through a housing that holds a bath of oil such that the dirt in the air is removed by the oil in the filter. The air then flows through a screen-type material to ensure any entrained oil is removed from the air. While in a dry filter system, paper, clot or a metal screen material is used to

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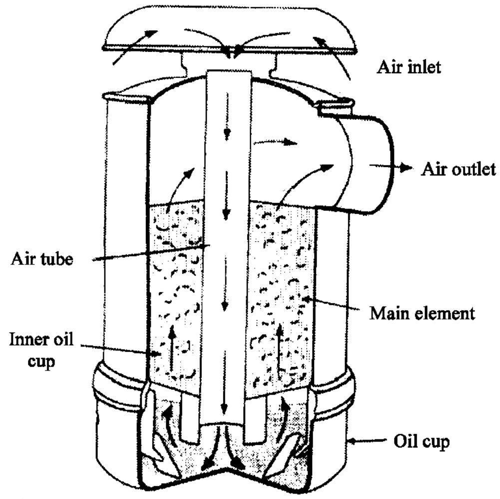

Fig. 1: Cut-away view of a wet filter system

catch and trap dirt before it enters the engine. A good air intake system is usually designed to intake fresh air from as far away from the engine as practicable. This is because it provides the engine with a supply of air that has not been heated by the engine's own waste heat.

It is a known fact that diesel engines requires close tolerances to achieve its compression ratio. Also, some most diesel engines are either turbocharged or supercharged, the air entering the engine must be clean, free of debris and as cool as possible. Moreoever, to improve a turbocharged or supercharged engines efficiency, the compressed air must be cooled after being compressed. The air intake system is designed to actualize these tasks. It was found that intake filters provide increased horsepower and torque, improved acceleration, fuel economy and maximum air flow for the test engine. Notably, by designing a more direct route for the air entering the engine, as well as a smoother interior surface for the intake, air resistance will be reduced and air flow increased.

Diesel engine performance: The performance of the modern marine diesel engines is critically dependent upon the performance of the turbocharger. It influences to a very significant extent, engine power output, specific fuel consumption, thermal loading and the ability of the engine to burn low grade of fuel successfully. Notably, mechanical reliability, resistance to corrosion and erosion and low noise level can be achieved with a good air filtration system, while pressure drop is minimized. An exploded view of typical turbochargers is shown in Fig. 2. According to Fig. 2 showing the position of the air intake filter, it is a known fact that diesel engines require close tolerance to achieve its compression ratio. Also, since most diesel engines are either turbocharged or supercharged, the air entering the engine must be clean,

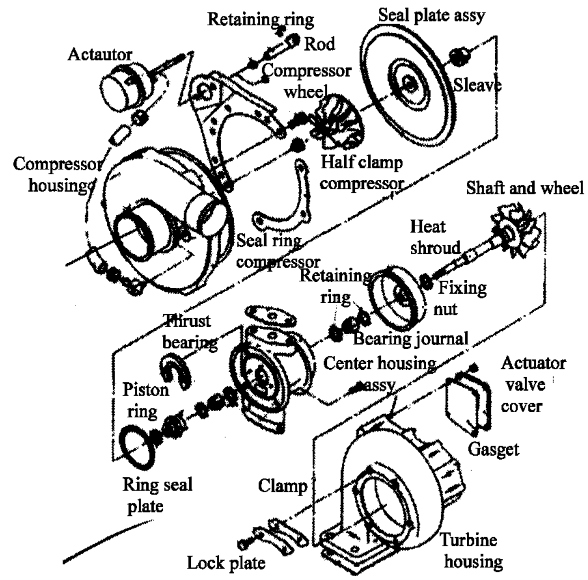

Fig. 2: Exploded view of an MTU 12V 396 TC 32 turbocharger

free of debris and as cool as possible. Moreover, to improve a turbocharged or supercharged engine's efficiency, the compressed air must be cooled after being compressed. The air intake system is designed to actualize these tasks.

Approaches to monitoring and data collection: Continuous and periodic monitoring are used for turbine generator monitoring and analysis. The process of continuous monitoring does not eliminate the need for periodic monitoring. The continuous monitoring system warns the operator about imminent problems. Periodic monitoring along with the collection of external data provides a means for analysis and projection of potential long-term problem both with respect to maintenance and operation (Ogbonnaya, 1998). Gas generator model data collections are capable of acquiring the necessary information to monitor and trend the state of engine health.

Other techniques: Mesbahi *et al.* (2004) presented a draft on diesel engine's fault diagnosis by means of ANNs. They stated that computer models of diesel engines have been used predominantly in the last two decades, thus becoming an important research tool in the design process. With the continuous development of personal computers i.e., faster processors with larger memories and reduced production costs, the use of these models implies a lower capital cost when running on smaller workstations. The result is a successful platform for cycle, engine and system simulation programs. It is also evident in Miller (2008) that a draft on estimate and control of turbocharger engines was presented. Here, two distinct approaches were used to eliminate the exhaust manifold pressure status.

These are the dynamic approach and the steady state turbocharger energy balance approach. It was observed that in the dynamic approach, the model was found to give good accuracy for some data sets but sufficient accuracy was not achievable for all available data sets. This approach was abandoned in favour of a steady-state turbocharger energy balance approach which have stood the test of time.

MATERIALS AND METHODS

The engine set up under investigation is depicted in Fig. 3. The engine model is MTU 12V396 TC32 diesel engine used for electricity generation in Port Harcourt, Rivers state of Nigeria. The engine characteristics are shown in Appendix A. The air flow is determined on the basis of pressure drop measurements across the inlet duct of the compressor. Pressure gauges were fitted on the down stream of the air intake filter. The pressure drop across the filter before entry into the compressor was monitored and compared with the load on the plant. The filter condition was proactively monitored using the model:

$$PDF = RCF[AMF]^2 \quad (1)$$

It was stated in the manufacturer's manual that the mass of air flow through the intake air filter is 60.771 kg min^{-1}. This was used to determine variable RCF which together with PDF is a measure of the health of the filter. The fact that average density of air at standard temperature and pressure is 1.293 kg m^{-3} was used to compute the mass flow rate of air having known the volume flow rate to be 47 m^3 min^{-1}. The use of component output variables for the healthy condition is shown in Fig. 4.

A software code named TOP A, written in qbasic programming language was developed using the engine component models. TOP A stands for Turbocharger Optimizer air system. This method of model-based computer programme is faster in diagnosing faults because it signals the limit of operation through instrumentation in the form of alarm. The flowchart for TOP A is shown in Fig. 5. While the qbasic program is shown in Appendix B.

This study would also contribute solution to prevent the unexpected failure/reduction in performance of a diesel engine air inlet system by making its performance effective using condition-based maintenance philosophy. This was realized by comparing the fluid performance data to that contained in the manufacturers manual and adopts measures using CM to achieve the optimum performance.

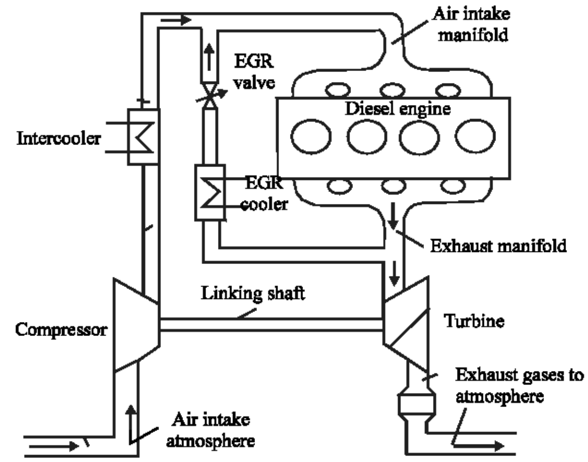

Fig. 3: Position of turbocharger in an engine setup

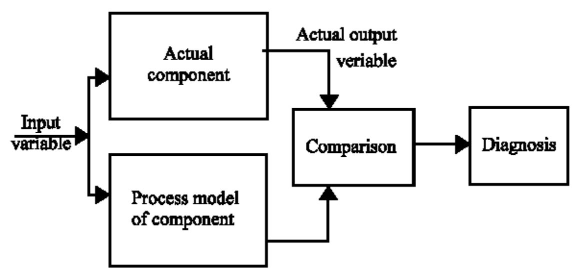

Fig 4: Component model for monitoring and diagnosis (Bergman, 1993)

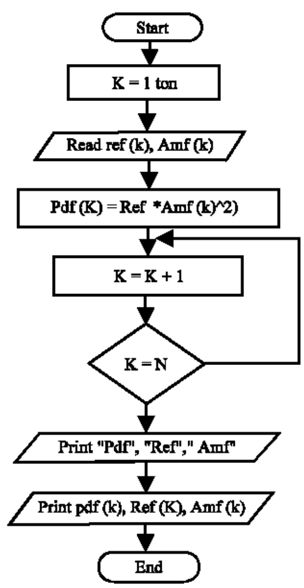

Fig 5: Flowchart for "TOP A"

RESULTS AND DISCUSSION

The volume flow rate and the corresponding air mass flow rate obtained from the CM session conducted for differential pressure drop, pdf across the air intake filter are shown in Table 1.

A graph of Pdf across intake air filter versus the square of mass flow rate $(AMF)^2$ shown in Fig. 6 reveals that the pdf across the air intake filter reduces as the square of air mass flow reduces.

The measured differential pressure was used to calculate the filter resistance coefficient, RCF which is also a measure of the filter blockage. The plot was used to predict the air mass flow and differential pressure at any point in time of the engine operation. The measured pdf was observed to remain at 0.85 bar for a very long time.

This means that the performance of the filter is optimum at this pressure. The data shows that the volumetric flow, air mass flow decreases as the pressure drop decreases. This vital information was also used to determine the variable RCF which together with pdf is a measure of the health of the filter and hence that of the engine.

Table 1: Air intake filter experiment results

V (m^3 min^{-1})	Amf (kg mm^{-1})	$(Amf)^2$ $(kg/min)^2$	Pdf (bar)
47.00	169.20	28628.64	0.90
45.68	164.45	27043.80	0.85
44.31	159.52	25446.63	0.80
42.90	154.45	23854.80	0.75
41.45	149.22	22266.61	0.70
39.94	143.78	20672.69	0.65
38.38	138.17	19090.95	0.60
36.74	132.26	17492.71	0.55
30.03	126.11	15903.73	0.50

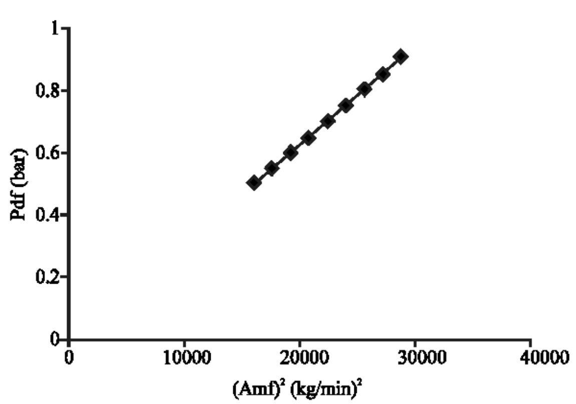

Fig 6: Variation of air intake differential pressure with square of air mass flow

CONCLUSION

A diagnostic method of trend performance monitoring using component model which can proactively monitor the health of diesel engine has evolved. The difficulties encountered in the analysis of data taken from air intake differential pressure have been simplified. This was made possible using the software code named TOP A written in qbasic programming language. This software enabled imminent failure to be detected.

The results obtained from the component models were programmed using qbasic programming language. It showed that the approach is handy to trend and monitor the performance of the diesel engine. These models were validated using performance data obtained from an operational diesel engine.

The study further revealed that it was possible to establish experimentally that the differential pressure is high enough to diagnose and clear any blockage the filter may experience over a long period. Also from the study, it was found that intake filters provide increased horsepower and torque, improved acceleration, fuel economy and maximum air flow for the test engine. Notably by designing a more direct route for the air entering the engine, as well as a smoother interior surface for the intake, air resistance will be drastically reduced and air flow optimally increased.

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NOMENCLATURE

AMF	=	Air Mass Flow (kg min^{-1})
RCF	=	Filter Resistance Coefficient
pdf	=	Pressure drop across air intake filter (bar)
EGR	=	Exhaust Gas Recirculation
CM	=	Condition Monitoring
Qbasic	=	Quick basic
V	=	Volume flow rate (m^3 min^{-1})

APPENDIX A

Characteristics of MTU 12V 396 TC32 diesel engine

Indicated power	945 kw
Mean indicated pressure	13.6 bar
Brake power	920 kw
Brake mean effective pressure	23.1 bar
Engine speed	1800 rpm
Engine rated torque	1050 Nm
Number of cycles	4

APPENDIX B

Program for an intake filter differential pressure calculation:

```
cls
Input "Enter the number of data you expect to input <=:",N
Dim pdf (N), Rcf (N), Amf (N)
For K= 1-N
  Read pdf (k), Amf (k)
  Rc(k) = pdf (k)/(Amf (k)^2)
Next K
cls
Print "Diff. Press", "mass flow rate", "Resistance Coefficient"
Lprint "Diff. Press", "mass flow rate", "Resistance Coefficient"
Print
Lprint
For I = 1 to n
  Print Tab (10); Pdf (I); Tab (32); Amf (I), Tab (58); Rcf (I)
  Lprint Tab (10); Pdf (I); Tab (32); Amf (I), Tab (58); Rcf (I)
Next I
Data 0.98, 66.771, 0.95, 58.91, 0.90, 55.81, 0.85,
Data 52.72, 0.80, 49.61, 0.75, 46.51, 0.70, 43.41,
Data 0.65, 40.30, 0.60, 37.19, 0.55, 34.11, 0.50, 31.01
```

Output results

Diff. pressure	Mass flow rate	Resistance coefficient
0.98	66.771	2.198114E-04
0.95	58.910	2.737446E-04
0.90	55.810	2.889472E-04
0.85	52.720	3.058216E-04
0.80	49.610	3.250510E-04
0.75	46.510	3.467118E-04
0.70	43.410	3.714655E-04
0.65	40.300	4.002241E-04
0.60	37.190	4.338094E-04
0.55	34.110	4.727149E-04
0.50	31.010	5.199558E-04

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