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Real Time Fault Detection and Diagnosis System onboard Engine Room

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Abstract

Recently smart and autonomous ship are appeared as hot issues internationaly because shipbuilding industry tries to look for way out of economic depression and environmental requirements of IMO with smart ship. Simultanously IMO tries to expel autonomous ship. A fault detection and diagnosis system is one of most important function in smart and autonomous ship. There are many methods to detect faults and diagnose in machine such as AI and big data treatment, but these methods have difficulties to train system, especially engines onboard are operated under very different situation and environment. This paper propose how to detect faults in running diesel engine without additional sonsor using CCs (Correation Coefficient) between the vital items. Over 10,000 operating data sets from engine room log book of 24 container ships, of which ages are spread out from new built ship to 21 years old ship, during 6 months are used in this paper. This paper develops fault detection and diagnosis sytem using staticical method based on collected data set.

Keywords:

Fault detection and diagnosis;
Correlation Coefficient;
Without additional sensors;
Smart and autonomous ship;
Engine room machineries.

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1. Introduction

Fault diagnosis process starts from detection of fault in running machine. It is very difficult to detect faults without special sensor in diesel engine because exhaust gas temperature from each cylinder vary depend on load. Power in diesel engine is created by combustion of fuel oil, so almost faults of diesel engine cause from combustion condition inside cylinder. Incomplete combustion inside cyliner causes late combustion and raises temperature of exhaust gas and reduces power. It also causes carborn deposite on the piston and occurs stuck of piston rings and damages. Exhaust gas flows to turbocharger to supply fresh air to the cylinder inside for next power cycle. There are close relationship between exhaust gas temperature of cylinder and other vital data, such as load, rpm, turbocharger inlet and outlet temperature and scavenging air pressure. This means high CCs (Correlation Coefficient) expected between vital data of diesel engine. If CCs between vital data are too small in comparision with normal case then abnormal situation is developed. Under the asumption that combustion in the cylinder may be same condition in an engine, CCs between each cylinder will be similliar each other. If certain CCs of cyliner are quite different with others, then abnormal combustion in the cyliner may be occurred. This idea can be applied to the heat exchanger, pumps and

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motors to detect faults of the system without additional sensors. Pump is connected with motor directly and effected each other, but CC between current of motor and outlet pressure of pump is maintained constantly in some range and same as in SD(Standard Deviation). This means this idea can be applicable to all machines in engine room[1]~[5].

This paper collected over 10,000 operating data from 6 months engine log books of 24 ships, of which ship particulars are summerized in Table 1. As shown in Table 1, samples are composed of several sister ships and proper aged ships to catch up characteristics and changes of CCs for various items of main engine by aging. Ship's age is spreaded out evenly from 0 to 4 years, 7 years and over 10 years.

Table 1. List of Ship Particular for study of the paper

SHIP'S NAME	DELIVERED	TONNAGE (GT)	MAIN ENG.			Date of Data (Logbook No.)	Aging (Years)
			MAKER, TYPE	RPM x OUT PUT (KW)	CLY x BORE x STROKE		
S_T	2017.7.7	18,064	HHI MAN B&W 6S60ME-C8.5(Tier II)	100.1 x 14927 (11140)	6 x 600 x 2400	2017.7~ 2018.1(1,2)	0
S_A	2017.10.24	18,064				2017.11~ 2018.5(1,2)	0
S_CH	2016.2.17	9,955	STX MAN 6S46ME-B8.3	122 x 8280 (6700)	6 x 460	2017.6~ 2017.12(5,6)	1
S_V	2016.4.22	9,955				2017.5~ 2017.11(5,6)	1
P_T	2014.3.7	9,988	HHI, MAN B&W 6S46ME-B8.2(Tier II)	122.1 x (7028)	6 x 460 x 1932	2017.5~ 2017.11(13,14)	3
P_P	2014.8.29	9,988				2017.5~ 2017.11(11,12)	3
S_L	2013.2.22	20,920	HHI MAN B&W 6S60 ME-C8.2(Tier II)	89 x 13860 (10270)	6 x 600 x 2400	2017.5~ 2017.11(17,18)	4
S_U	2013.3.1	20,920				2017.6~ 2017.12(17,18)	4
SS_P	2013.3.8	20,920				2017.6~ 2017.12(17,18)	4
L_S	2000.9.29	7,409	HHI, MAN-B&W 8S35MC-MK6	170 x 7600 (5600)	8 x 350 x 1400	2017.3~ 2017.10(64,65)	7
B_S	2000.12.8	7,409				2017.3~ 2017.10(1,2)	7
S_A	2009.12.14	9,522	STX-MAN B&W 6S46MC-C	129 x 10710 (7860)	6 x 460 x 1932	2017.3~ 2017.9(1,2)	7
S_C	2010.3.31	9,520	STX-MAN B&W 6S46MC-C	129 x 10710 (7860)	6 x 460 x 1932	2017.5~ 2017.11(28,29)	7
S_S	2010.6.30	9,520				2017.5~ 2017.11(27,28)	7
S_P	2010.8.22	9,520	STX-MAN B&W 6S46MC-C	129 x 10710 (7860)	6 x 460 x 1932	2017.3~ 2017.9(26,27)	7
S_E	2010.10.15	9,520				2017.5~ 2017.11(26,27)	7
P_U	2007.7.20	9,522	STX-MAN B&W 6S46MC-C	129 x 10710 (7860)	6 x 460 x 1932	2017.4~ 2017.10(38,39)	10
P_Z	2005.2.7	9,522				2017.12~ 2018.5(50,51)	12
P_Y	2005.5.6	9,522				2017.6~ 2017.12(47,48)	12
P_PR	2004.2.20	7,406	SSHI-MAN B&W 8S35MC-MK7	173 x 8080 (5920)	8 x 350 x 1400	2017.7~ 2018.1(52,53)	13
P_PA	2003.11.28	7,406				2017.5~ 2017.11(52,53)	14
M_S	1996.12.28	3,997	SSHI-MAN B&W 6L35MC	200 x 4560 (3402)	6 x 350 x 1050	2017.6~ 2017.12(79.80)	21

2. Research Method

This paper use Pearson CC analysis to detect faults of diesel engine. As well know CC can be calculated as following equation.

$$\rho_{xy} = Cov(X,Y)/\sigma_x \cdot \sigma_y, -1 \leq \rho_{xy} \leq 1 \quad (1)$$

$$Cov(X,Y) = \frac{1}{n}\sum_{i=1}^{n} (x_i - \mu_x)(y_i - \mu_y) \quad (2)$$

where

$$\mu_x = \frac{1}{n}\sum_{i=1}^{n} x_i, \quad \mu_y = \frac{1}{n}\sum_{i=1}^{n} y_i$$

$$\sigma_x^2 = \frac{1}{(n-1)}\sum_{i=1}^{n} (x_i - \mu_x)^2$$

$$\sigma_y^2 = \frac{1}{(n-1)}\sum_{i=1}^{n} (y_i - \mu_y)^2$$

x:array1, y:array2

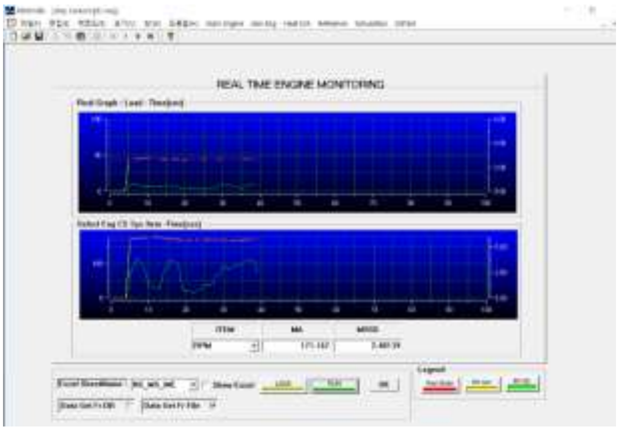
Using above equation, CCs of vital parameter of all operating data are caculated and summarized depend on the ship's age. Table 2 shows calculated CCs of vital parameters. All CCs of vital paremeters in Table2 are calculated using above equations. The CC between load and rpm shows how much fuel input to the engine is changed effectivly to rpm. If the CC between load and rpm is low, it means fuel input into the engine is not used effectively to raise rpm because of high friction by bottom fouling or opposite current.

Table 2. Summary of change of CC for vital items by aging of ship

years	0	1	3	4	7	10	12	13	14	21
Cyl TexhAvr	0.8575	0.876725	0.76195	0.845917	0.5712	0.5441	0.672075	0.3907	0.44705	0.5575
Load-Cyl Avr	0.7159	0.80315	0.449825	0.7898	0.288117	0.00385	0.169625	0.0921	0.18655	0.0695
rpm-Cyl Avr	0.66335	0.77105	0.22485	0.77565	0.282075	0.08025	0.1617	0.09045	0.11805	-0.0745
Load-T/C Tin	0.5525	0.7255	0.44225	0.764	0.24025	-0.2185	0.24575	-0.083	-0.094	0.077
rpm-T/C Tin	0.5145	0.6875	0.24075	0.707333	0.24525	-0.13	0.30025	-0.681	-0.08	-0.087
Load- T/C Tout	-0.52075	-0.0395	-0.173	-0.16133	-0.45483	-0.376	-0.4985	0.022	-0.07	-0.051
rpm- T/C Tout	-0.53275	-0.05925	-0.1235	-0.15517	-0.40342	-0.2445	-0.493	0.022	-0.0685	-0.1515
Load-T/C rpm	0.6025	NA	0.36	0.901	0.734	0.719	0.2175	-0.44	0.438	-0.066
rpm-T/C rpm	0.4795	NA	0.24725	0.86175	0.6921	0.5875	0.26575	-0.342	0.3505	-0.222
Load-ScavP	0.8895	0.87025	0.51275	0.898167	0.811	0.7865	0.72125	0.559	0.663	0.3725
rpm-ScavP	0.80575	0.83325	0.25525	0.859333	0.768083	0.6245	0.72575	0.1545	0.6285	0.438
Load-RPM	0.7295	0.83075	0.3555	0.752833	0.692083	0.5655	0.72175	0.506	0.648	0.448

The CCs between load and rpm with scavenging air pressure represents how effectively scavenging air is supplied by turbocharger. It is very unique that CCs of load and rpm with turbocharger outlet temperature are negative because when load or rpm is high, turbocharger makes high power to supply more scavenging air to the cylinder by making big heat drop.

This paper develops fault detection and diagnosis system for diesel engine in real time using C++ based on this idea and Table 2. Figure 1 shows selected items of diesel engine are montored in real time and Figure 2 shows how to detect faults of diesel engine. Criterion of fault detection is predefined by input FDCC (Fault Detection CC) which are decided by expert or chief engineer onboard.



Tabe 2 is results of series studies of authors. Auhtors studied about how the CC of the vital parameter of diesel engine changes depend on the ship's age by investigation of 24 ships of which ages is spread out from 0 to 21 years shown in Table 1. When the expert or chief engineer decide the FDCC he can refer the results of this study[1] ~[5]. Figure 3 and 4 show a part of the results which shows CCs of scavenging air pressure and those of cylinder average with rpm and load changing trend of vital parameter depend on ship' age.

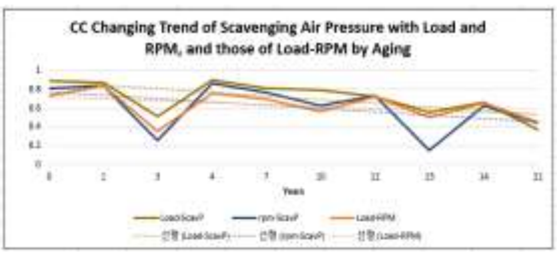


Figure 3. *CC changing trend of scavenging air pressure with load and RPM, those of Load and RPM*

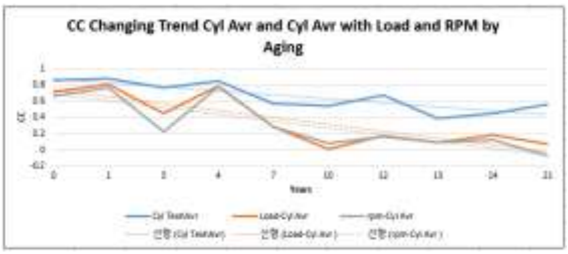
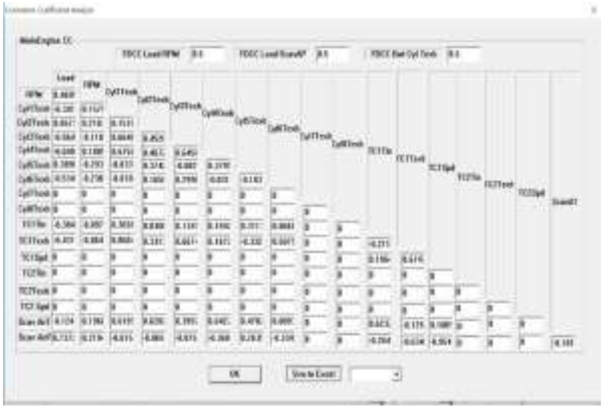


Figure 4. *CC changing trend of cylinder average and cylinder average with load and RPM*

Figure 5 shows CC table calculated when the button of See CC Table in Figure 2 is clicked. This table can be saved by button of Save to Excel in Figure 5 and used to analyze the characteristics of the engine depend on the voyage. Figure 6 show fault diagnosis of main engine. Detected faults are shown in the figure as LED style and information for faults and diagnosis, recommendation for maintenance at each dedicated edit box. Fault detection is decided by FDCC, but diagnosis is decided by decision making modules which investigate related CC, such as CCs between each cylinder, CCs between each cylinder and scavenging air pressure, average CC between load and each cylinder, CC between load and scavenging air pressure etc.

If CC between load and rpm is relatively low in comparison with other voyage or reference by the result of study [5], fuel consumption may not be changed rpm of engine by high resistance of ship skin and opposite current and wind. If one or several CCs between each cylinder is low in comparision with each other, the combustion status inside the cylinder may not good by bad fule valve, not enough fresh air inside cylinder or low compression pressure etc. The reason in these case will be found by investigation of input information about overhauling and running hours of engine components and CC analysis.



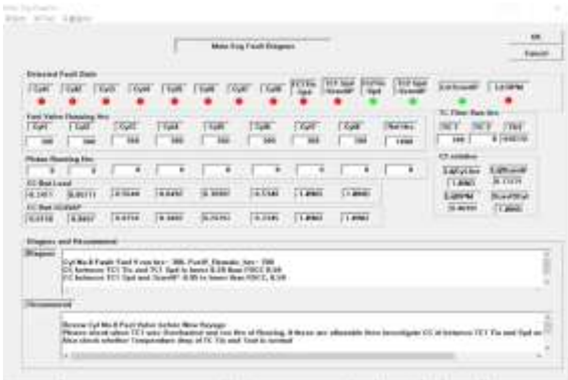


Figure 5. *CC table of vital parameter for main engine*

3. Results and Analysis

Figure 7 shows CC between load and outlet temperature of turbosharger depend on aging of ship. The CC between load and turbocharger outlet temperature is negative, because when the load increases, temperature of turbocharger outlet is decreased. This CC is close to zero according to ship's aging, sometimes it crosses over zero to positive CC in severe case. If this CC is positive, when the load increases, then temperature of turbocharger outlet also increases. This results in decrease power of turbocharger and supply of scavenging air decreases and may be reasons of incomplete combustion.

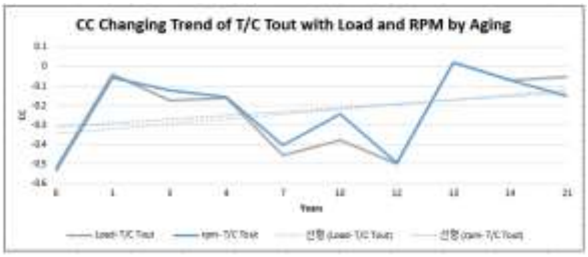


Figure 7. *CC between load and T/C Tout changing trend by ship's aging*

Table 3 shows descriptive statistics and CC with load of 14 years old ship. The CC of load and turbocharger outlet temperature is positive and while CC between load and turbocharger rpm is negativce. These mean when load increase, turbocharge outlet temperature increase also. The result of this is that power of turbocharger decrease and make shortage of supply for scarvenging air. To find the reason let's investigate CC between cylinder each other. Table 4 shows CCs between each cylinder. The CC between each cylinder are very high except CCs with cylinder 6. So reason for these phenpmena seems to be bad condition of fuel valve in cylinder 6. If the same situation is occurred after renewal of fuel valve for cylinder 6, resistance of turbocharger system including blower should be

Table 3. Discriptive statistics and CC with load of 14

	Avr	SD	N
GovPos	8.524	0.9816	311
RPM	137.86	13.3268	311
ExhGas1_T	395.37	34.619	311
ExhGas2_T	396.16	38.04	311
ExhGas3_T	402.44	33.55	311
ExhGas4_T	402.17	36.341	311
ExhGas5_T	387.26	49.408	311

	GovPos
GovPos	1
RPM	.744**
ExhGas1_T	.619**
ExhGas2_T	.602**
ExhGas3_T	.620**
ExhGas4_T	.646**
ExhGas5_T	.598**

		ExhGas1_T	ExhGas2_T	ExhGas3_T	ExhGas4_T	ExhGas	ExhGas6_T	ExhGas7_T	ExhGas8_T
Ex	ExhGas1_T	1							
Ex	ExhGas2_T	.941**	1						
T/	ExhGas3_T	.927**	.944**	1					
T/	ExhGas4_T	.843**	.851**	.880**	1				
T/	ExhGas5_T	.932**	.961**	.928**	.825**	1			
Sc	ExhGas6_T	.213**	.235**	.242**	.205**	.253**	1		
Sc	ExhGas7_T	.848**	.821**	.830**	.794**	.818**	.207**	1	
	ExhGas8_T	.764**	.759**	.777**	.695**	.754**	.193**	.699**	1

aged ship investgated investigated. The CC changing trend by ship aging is very important reference and criterion for fault diagnosis system by CC. With this reference fault detection and diagnosis for diesel engine using CC without additional sensors seems to be usful.

4. Conclusion

In this paper authors develop fault detection and diagnosis system using CC based on previous series studies[1] ~[5]. In previous work CC changing trend by ship aging for vital parameter of diesel engine was studied with 6 months operating data of 24 ships of which age are spread out from new built ship to 21 years old ship. Every CC of vital parameter of diesel engine changes to be a small relation depend on ship age except temperature of turbocharger outlet temperature. The CC between load and outlet temperature of turbocharger changes from negative big close to zero, sometimes cross over to positive. The CC of vital parameter of diesel engine gives us important knowledge about operation condition. If CCs of vital parameter of diesel engine are analysed each other, then various reasons of faults can be derived. Using the results of previous studies this paper develops fault detection and diagnosis in real time for diesel engine. This paper confirms the method using CC of vital parameter for diesel engine is usful to detect fault and diagnosis for diesel engine in real time without any additional sensors. This method can extend to heat exchanger, pump and motor system in engine room.

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