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A Study on the Correlation Analysis of the Present Status of Turbo Pumps Installed in Ships

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Abstract : Now days, various types of ships are operated to transport both cargo and passengers all around the world. Most of the important auxiliary machinery installed in those ships is fluid machinery such as pumps, compressors, and fans. A large percentage of fluid machinery is pumps which are classified as turbo and positive displacement pumps. This paper analyzes only turbo pumps out of the two types. This thesis has two aims: (a) to analyze the present status of pumps installed in merchant and training ships and (b) to find the correlation among sea going pump kW, port pump kW, GE kW, ME MCR, number of pumps, ME kgf, pump kgf. Based on the ship's type, my paper seeks to find special characteristics as a result of analyzing head, flow rate, and kW. Moreover this paper analyzes and compares number of pumps, rpm of pumps, pump kW/ME MCR and pump kW/GE kW under the conditions of seagoing and berthing according to the ship's type.

In conclusion, ① For the exact comparison, information on the head, kW, flow rate, number of pumps by ship's type, the pump installation status of the Merchant Ships and Training Ships were tabulated and compared in this paper. ② In order to qualify one ship as the delegate ship, several methods were used. The result of the examination indicates that the chosen ships could be justified as a suitable representation of ships of their own type. ③ The correlation of several values(total pump kW, port pump kW, GE kW, seagoing pump kW, pump weight, ME weight, ME MCR, number of pumps and ME kW) could be obtained.

Key words : Turbo pump, Correlation analysis, Merchant ships, Training ships

Nomenclature

F.O. : Fuel Oil
GE : Generator Engine
G/T : Gross tonnage
kW : kilowatt
LNGC: Liquified Natural Gas Carrier
L.O. : Lubricating Oil
MCR : Maximum Continuous Rating
ME : Main Engine
T/S : Training ship

1. Introduction

Currently, there are numerous types of ships[1] that are operated globally at sea.

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Most of the auxiliary machineries that are installed in a ship are fluid machinery [2] such as pumps, compressors and fans. A large percentage of fluid machineries in the ship are pumps. However, the only research that has taken place on pumps is on the types of pumps, their specifications, internal fluid flow and pump performance[3]. Practically, no systematic study has taken place on the relation between ship's type and the using status and characteristics of ship's pumps. Pumps are important machineries for cooling, lubricating, supplying of fuel oil to main engine and auxiliary machineries and loading/ unloading in the ships, most of which are classified into turbo and positive displacement types except a few special pumps.

This paper is based on the present state of installation of turbo pumps in the way of ① - ④ below.

①Analysis of ship's characteristics through comparing and analyzing pressure head, flow rate, kW and number of pumps classified by ships' type.

②Characterization according to the distribution of turbo pumps by ship's type.

③Comparison and analysis of the power of dividing pump by ME MCR under the conditions of seagoing and berthing.

④Analysis of the characteristics by means of dividing weight of pump by weight of ME.

Based on the results, the correlation between the variables in ①②③ and ④ stated above are analyzed.

First of all, by simultaneously testing all the ships types and comparing them separately according to ship's type to identify the correlation between pump and the above parameters.

The varieties of ships are broad and have special characters. We would like to verify whether the ship that was chosen for this study can represent the diversity of ships.

2. The status of pump installation classified by ship's type

The following tabulated information are derived from a ship that is currently operating at a shipping and also from LNGCs that are operating under the Korean flag. The biggest ships classified by ship's type as illustrated in Fig.1 were selected for the study and Table 1 shows the specifications of the selected ships.

The power in kW, head, flow rate of turbo pumps of all types of ships were analyzed and Figs. 2~6 show the characteristics of the ships analyzed with the graph for Bulk Carrier, Car Carrier and Training Ship(Hannara) omitted. The vertical axis on the left of the graph indicates pump kW which is the output kW of one pump and sums up the kW of several pumps of same type, while the vertical axis on the right of the graph shows pump flow rate and head and the vertical axis on the left side shows pump kW. All data used in the paper is based on the data booklet and electric load analysis of the finished plan issued by the shipyard.

2.1 The usage characteristic of turbo pumps classified by ship's type

In LNGC, the boiler feed water pump

driven with high speed turbine to feed water into high pressure boiler has the biggest value of kW per pump, and in case of Oil Tanker cargo oil pump driven by turbine has also the biggest value of kW per pump. Cargo oil pump for discharging cargo oil uses the turbine driven by the steam generated from boiler as a power source to drive the pump because the generator engine need to have excessively big capacity to run the pump because of the big flow rate of the pump. Water ballast pump in Oil Tankers is also driven by a turbine.

In the case of Container Ships, main L.O. pump has the biggest flow rate and the pump lubricating ME would be installed in proportion to the capacity of ME. Even though water ballast pump of Container Ship also has big flow rate, main L.O. pump has the biggest flow rate because Container Ship has biggest ME compared to other ships because it has an opportunity to have liner service. Coal/Ore Carriers have a large water ballast pump due to the same reason as Bulk Carriers. In case of T/S Hanbada main cooling seawater pump has the biggest value of kW. So far, it can be noted that all types of ship have their own features in relation to kW of turbo pumps per pump.

The maximum head is observed on the boiler feed water pump in all ships. Because in all cases high head pump is needed to feed water into the inside of the high pressure boiler.

In the case of flow rate, the maximum flow rates are held by the LNGC's main cooling sea water circulation pump which cools the main condenser during navigation or while at berth, the Oil tanker's cargo pump which is used for prompt loading and discharging, lastly the Coal/Ore Carrier's water ballast pump which has a high capacity due to the need for quick adjustments of ballast during loading and discharging of cargo. Main cooling seawater pumps of Container Ship and T/S Hanbada also have the maximum flow rate.

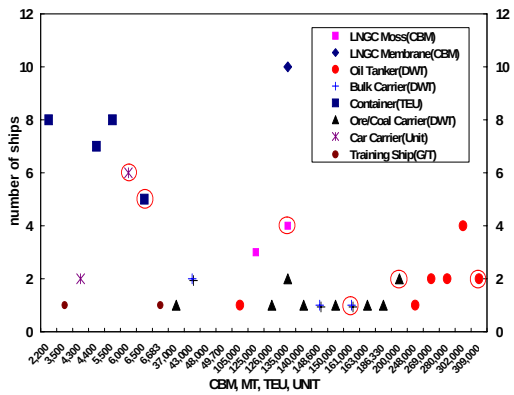

Fig. 1 The subjects of ships for research

Table 1 Specifications of ships for research

	Built (year)	Length(LOA) (m)	Deadweight Grosston(MT)	M/E M.C.R. (kW)	M/E N.C.R. (kW)	G/E output (kW)
LNGC(MOSS)	2000	289	77,584	29,082	26,174	3250 x 3
oil tanker	2005	333	309,000	29,127	25,287	1000 x 3
bulk	1997	280	161,121	17,091	15,928	600 x 3
container	2001	304	80,500	66,844	60,613	3000 x 4
ore/coal	1990	298	200,100	15,123	13,609	560 x 3
car carrier	1997	200	21,505	14,511	13,057	1180 x 3
T/S Hannara	1993	93	3,640	2,982	2,535	480 x 3
T/S Hanbada	2005	117	6,686	6,062	5,153	960 x 3

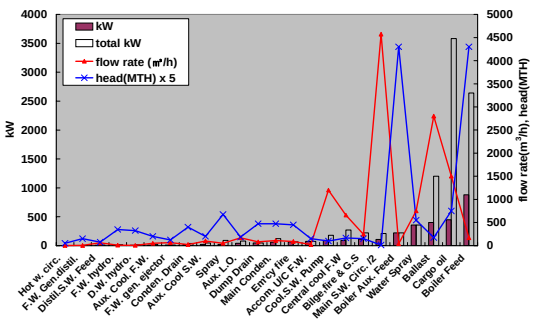

Fig. 2 LNGC turbo pump

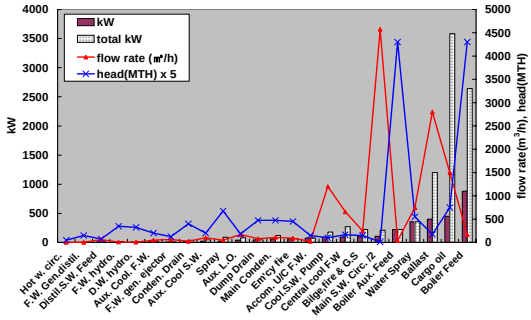

Fig. 3 Oil tanker turbo pump

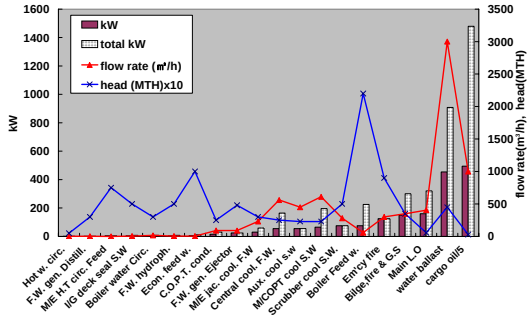

Fig. 4 Container turbo pump

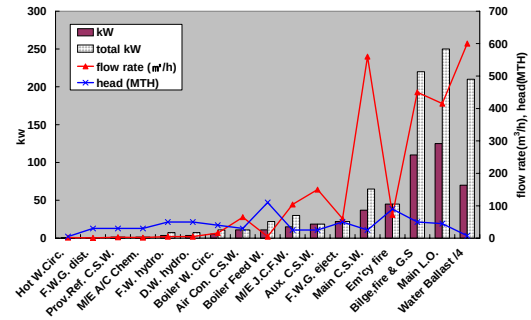

Fig. 5 Ore/coal turbo pump

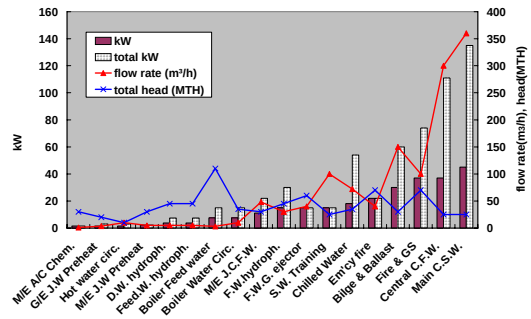

Fig. 6 T/S Hanbada turbo pump

2.2 The distribution feature of turbo pump classified by ship's type

Fig. 7 shows the total number of turbo pumps according to ship's type. Special ships like LNGC, Oil Tanker have many pumps, and T/S Hanbada also has many pumps as it's ME is a combined electronic engine and conventional cam fitted engine.

Fig. 8 displays the total number of pumps according to ship's type to compare the ships selected for this study with the unselected ships. There was no great deviation classified by ship's type in the amount of pumps to be represented as model pumps for the research, all types of ship have similar number of pumps.

Fig. 9 indicates the standard deviation[4] and the mean of the total number of pumps according to ship's type and the ships selected for this study. The mean is the average value of the group. This Scatter diagram indicates the scattered extent of the value of variety, and the unit of measuring the variation extent or scattered state of data value is in a state of variance. If it scatters widely from the mean, variance is large. On the other hand, if it is closed to the mean, variance is small. A square root of the variance is the standard deviation. Equation (1) is mean, equation (2) is variance, and equation (3) is standard deviation.

$$\mu = \frac{(X_1 + X_2 + \cdots + X_n)}{N} = \frac{\sum_{i=1}^{n} X_i}{N} \quad (1)$$

$$\sigma^2 = \frac{\sum_i^n (X_i - \mu)^2}{N} \quad (2)$$

$$\sigma = \sqrt{\frac{\sum_i^n (X_i - \mu)^2}{N}} \quad (3)$$

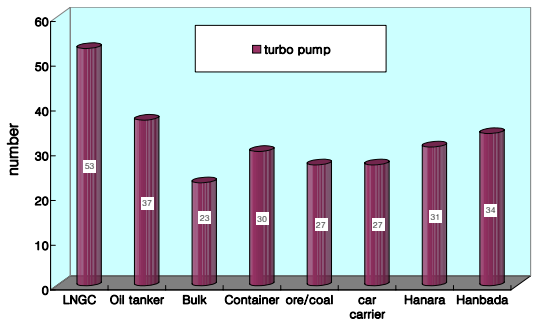

Fig. 7 The number of pumps according to ship's type

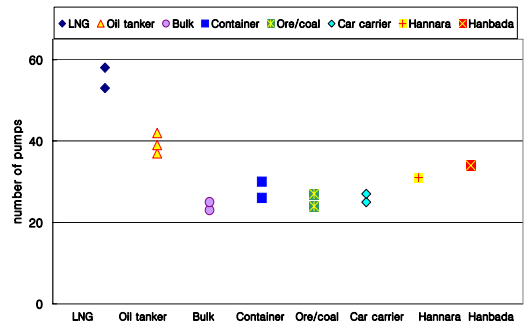

Fig. 8 Comparison between ship for research and ships not for research for the number of pumps according to ship's type

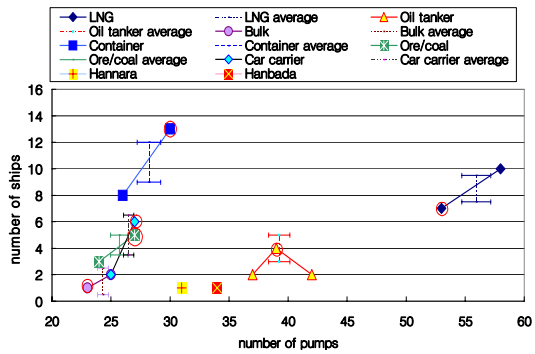

Fig. 9 Standard deviation, mean for the number of pumps according to ship's type

2.3 The power characteristics of pump kW vs. ME MCR by ship's type

Fig. 10 shows the value of pump kW divided by ME MCR under the conditions of seagoing and berthing according to ship's type. The high value indicated during berthing means that there are many driving pumps to discharge and the high value indicated during the seagoing condition means that there are no special ship's pumps to be driven at the discharging port and shore facilities would be used for discharging. Specially, the reason why LNGC and Oil Tanker indicate a high value under the berthing condition is that the ships transporting liquid cargoes need big capacity cargo pumps that require high kW. The value of pump kW versus ME MCR under the seagoing condition is similar values(1.20 ~ 5.03) when compared to the value under berthing condition in most types of ships, although all ship's data are different.

Fig. 11 shows the value of pump kW versus ME MCR and those pumps selected for this study were compared with other pumps which was not selected as an case ship for this research to identify whether the pumps selected for this study can delegate other pumps. It should be noted that the values of the same type of ships are almost the same. In addition Fig. 12 shows details the value in Fig. 11 and shows the standard deviation, mean and selected case ship separately compared with the value of unselected object ships. As the graph should be noted the values are placed mostly on the left side of the graph except LNGC and Training Ships. It would be understood that diesel ships

have similar features regardless of the ship's type.

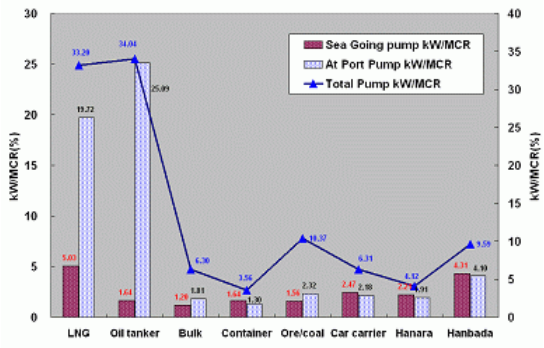

Fig. 10 Power characteristics of pump kW vs. ME MCR

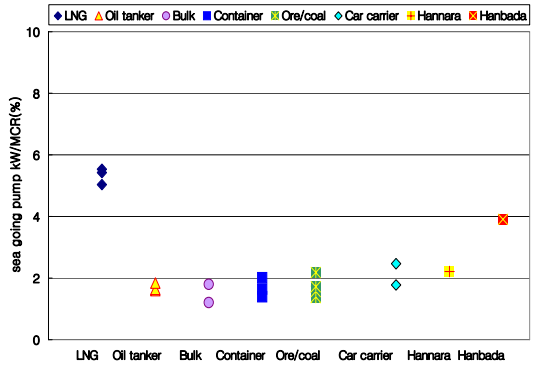

Fig. 11 Comparison between ship for research and ships not for research for the power characteristics of seagoing pump kW v.s. ME MCR

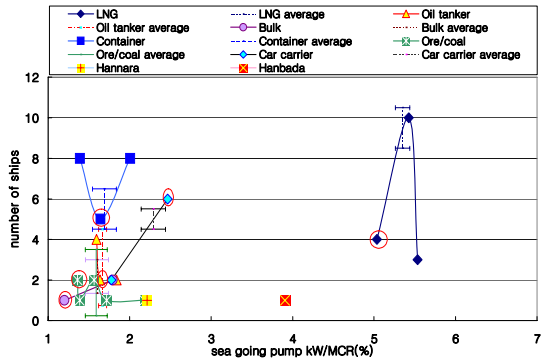

Fig. 12 Standard deviation, mean for the power characteristics of seagoing pump kW vs. ME MCR

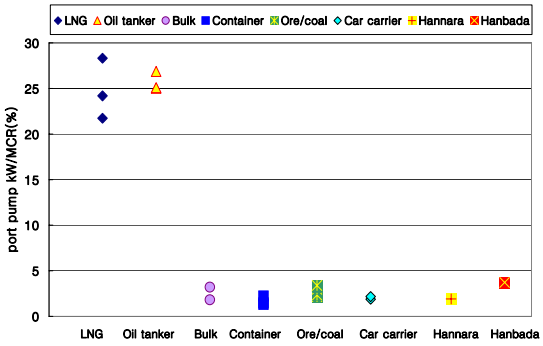

Fig. 13 Comparison between ship for research and ships not for research for the power characteristics of port pump kW vs. ME MCR

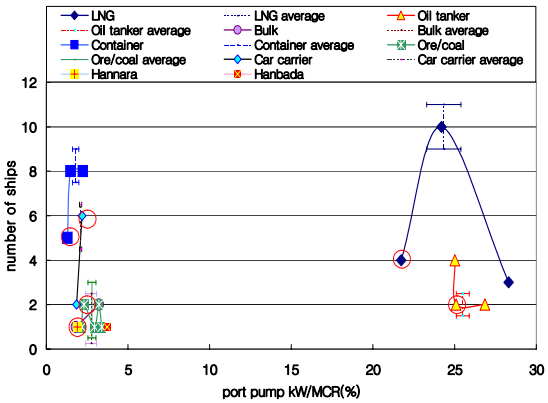

Fig. 14 Standard deviation, mean for the power characteristics of port pump kW vs. ME MCR

Fig. 13 and 14 indicate the value of pump kW/ME MCR under the berthing condition. The most important feature in contrast to the seagoing conditions is that the values of LNGC and Oil Tanker are placed on the right side of the graph. This means that the ships need more power for cargo oil pumps while at berth.

2.4 The feature of pump weight vs. ME weight by ship's type

Fig. 15 shows the value of the Turbo

pump weight (in case of more than one pump the values are summed up) versus the ME weight according to ship's type. The LNGC's ME is a turbine which is light, but for Container ship's, due to its principle for sharp time keeping in frequent arrivals and departures in ports as a liner service, it has a larger ME compared to other ships. Two Training Ships have the higher value than other Merchant Ships because they need basically all kinds of pump, even though they have small ME.

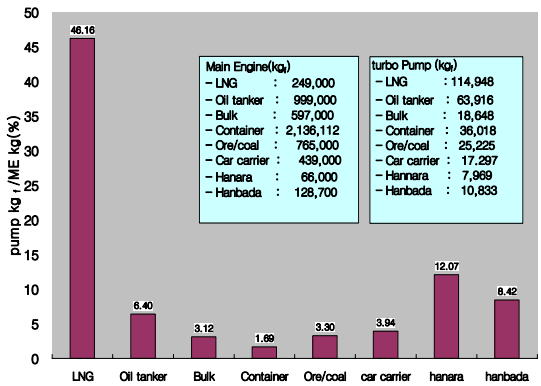

Fig. 15 The weight characteristics of pump vs. ME

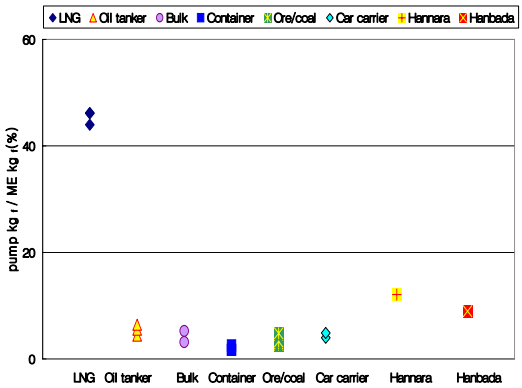

Fig. 16 Comparison between ship for research and ships not for research for the mass characteristics of pump vs. ME

Fig. 16 shows that various methods were carried out to examine whether the ship selected for this study can delegate the other ships and the value in the graph positioned almost in one place.

Fig. 17 indicates that LNGC has light turbine ME but the weight of pump is turned out as heaviest one.

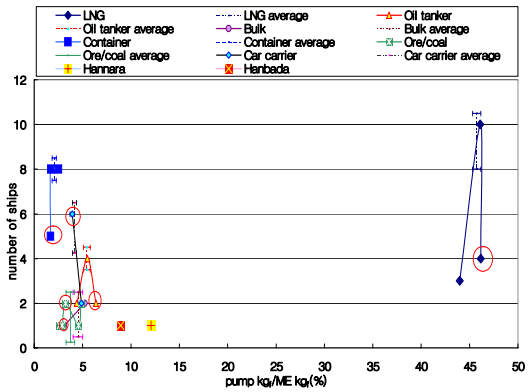

Fig. 17 Standard deviation, mean for the weight characteristics of pump vs. ME

3. Analyzing correlation of all kinds of parameter classified by ship's type

Table 2 compares the values of each parameter according to ship's type. Table 3 analyzes correlation of parameters by using the Pearson's correlation coefficient[5] procedures of Statistical Package for the Social Science (SPSS) to analyze the organic relation of the parameter. Pearson's correlation coefficient would be indicated by 'r' and the statistical definition equation used is equation (4).

$$r = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{(n-1)S_X S_Y} \quad (4)$$

where, 'n' is the size of specimen, Sx is the standard deviation of parameter X and Sy is the standard deviation of parameter Y.

Correlation coefficient is an index measuring the extent of the first relation between two parameters. This indicates the relation direction of the first degree and extent of relation between two parameters. The extent of relation that correlation coefficient means is as follows.

- 1.0~0.7(-1.0~-0.7): Very strong relation
- 0.7~0.4(-0.7~-0.4): Considerable relation
- 0.4~0.2(-0.4~-0.2) : Slight relation
- 0.2~0.0(-0.2~-0.0) : No relation

Table 3 shows that most parameters have correlation with each other. Especially, Figure18 indicates five top rank items which have strong relation and Fig.19 indicates relatively low rank items which have no relation.

After comparing all types of ship at the same time, LNGC (3 types), Oil tanker (3 types), Container Ship (3 types) and Coal/Ore Carrier (5 types) were analyzed the correlation of each ships according to ship's type. Figure 20 shows that closer correlation was identified than the case of comparing all ships together. Moreover, Fig.20 is the result which takes an average of each correlation classified by ship's type. In this graph, the most related ship's type in relation to the value of relation is Container Ship of 0.96, and LNGC of 0.85, Oil tanker of 0.73, Coal/Ore Carrier of 0.68. Thus, the value of each ship's type is higher than the value of all ships' average, because the average value of all ships is 0.50.

Table 2 Various values according to ship's type

	LNG	Oil tanker	Bulk	Containe	Ore/coal	Car carrie	Hamara	Harbada
sea going pump kW	1464.15	477	205.1	1097.6	236.55	357.75	65	264.9
port pump kW	6318.75	7308	309.3	869.1	360.3	316.25	56.9	232.1
Total pump kW	9666	9916	1077	2378.1	1553	915.75	323.9	592.5
GE kW	9750	3000	1800	12000	1680	3540	1200	2880
ME MCR(kW)	29082	29127	17091	66844	15123	14511	2982	6062
number of pumps	53	37	23	30	27	27	31	34
DWT, G/T(ton)	77584	309000	161210	80600	200100	21505	3460	6686
ME weight(kg)	249000	999000	597000	2136112	765000	439000	66000	128700
pump weight(kg)	114948	63916.5	18648	35988	24785	17297	7969	11517

Table 3 Correlation coefficient of various values

Correlations

		sea goin pump kW	rt pump k	total pump kW	GE kW	ME MCR	number f pump	WT, G/T	E weight	mp weig
sea going pu	Pearson Cor	1	.558	.630	.931*	.713*	.733*	-.023	.380	.832*
	Sig. (2-taile		.151	.094	.001	.047	.039	.956	.354	.010
	N	8	8	8	8	8	8	8	8	8
port pump k	Pearson Cor	.558	1	.994*	.307	.270	.768*	.548	.053	.874*
	Sig. (2-taile	.151		.000	.459	.517	.026	.159	.901	.005
	N	8	8	8	8	8	8	8	8	8
total pump k	Pearson Cor	.630	.994*	1	.381	.334	.786*	.545	.103	.915*
	Sig. (2-taile	.094	.000		.351	.418	.021	.162	.809	.001
	N	8	8	8	8	8	8	8	8	8
GE kW	Pearson Cor	.931*	.307	.381	1	.855*	.497	-.155	.592	.584
	Sig. (2-taile	.001	.459	.351		.007	.210	.713	.122	.129
	N	8	8	8	8	8	8	8	8	8
ME MCR	Pearson Cor	.713*	.270	.334	.855*	1	.148	.218	.913*	.387
	Sig. (2-taile	.047	.517	.418	.007		.726	.603	.002	.344
	N	8	8	8	8	8	8	8	8	8
number of pu	Pearson Cor	.733*	.768*	.786*	.497	.148	1	-.026	-.213	.885*
	Sig. (2-taile	.039	.026	.021	.210	.726		.952	.613	.004
	N	8	8	8	8	8	8	8	8	8
DWT, G/T	Pearson Cor	-.023	.548	.545	-.155	.218	-.026	1	.356	.302
	Sig. (2-taile	.956	.159	.162	.713	.603	.952		.386	.467
	N	8	8	8	8	8	8	8	8	8
ME weight	Pearson Cor	.380	.053	.103	.592	.913*	-.213	.356	1	.062
	Sig. (2-taile	.354	.901	.809	.122	.002	.613	.386		.884
	N	8	8	8	8	8	8	8	8	8
pump weight	Pearson Cor	.832*	.874*	.915*	.584	.387	.885*	.302	.062	1
	Sig. (2-taile	.010	.005	.001	.129	.344	.004	.467	.884	
	N	8	8	8	8	8	8	8	8	8

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

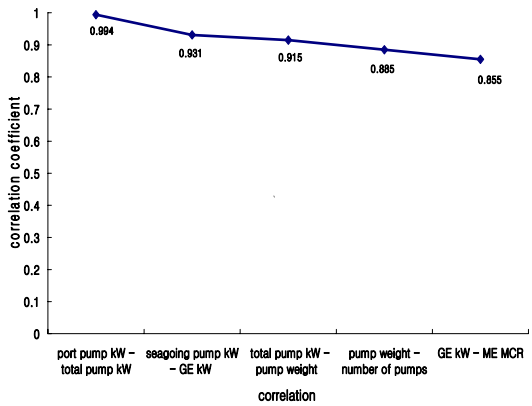

Fig. 18 Correlation coefficient of various values (high rank5)

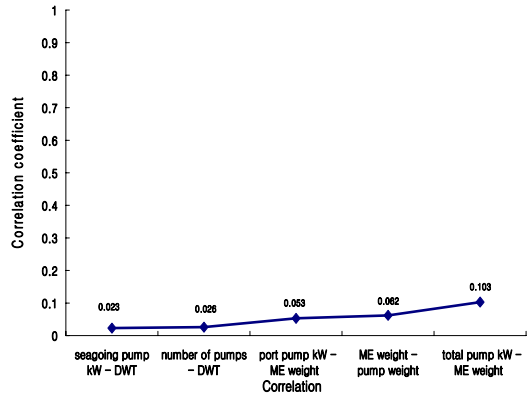

Fig. 19 Correlation coefficient of various values (low rank 5)

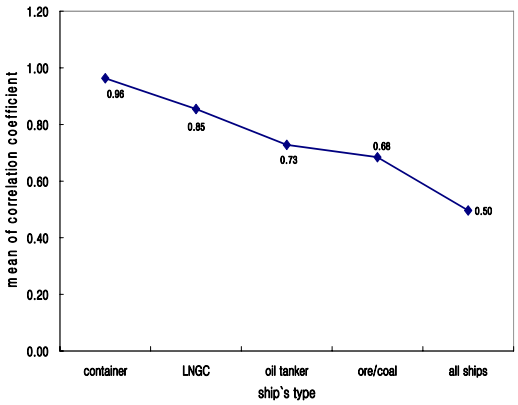

Fig. 20 Mean of correlation coefficient according to ship's type

4. Conclusion

The following conclusions are drawn from the research that was carried out in relation to the using status and characteristic of turbo pumps installed in 6 types of Merchant Ship and 2 types of Training Ship classified by ship's type.

1. Diagrammed the pump installation status of the Merchant Ships and Training Ships and compared head, kW, flow rate, number of pumps by ship's type.

2. In order to qualify one ship as the delegate ship, several methods were used. The methods are listed below; ①the distribution of turbo pump by ship's type, ②the feature of total kW vs. ME MCR by ship's type, ③the feature of pump weight vs. ME weight by ship's type.

The result of the examination indicates that the chosen ships could be justified as a suitable representation of ships of their own type.

3. From the values received from 1 and 2 (total pump kW, port pump kW, GE kW, seagoing pump kW, pump weight, ME weight, ME MCR, number of pumps and ME kW), the following correlation could be obtained.

① as a result of separating the ship's type and analyzing their correlation, it was concluded that there was a close relationship between them.

② as a result of analyzing the correlation of all types of ships the average was calculated to 0.50 which meant that the correlation was lower than dividing the types of ships.

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