UNITECH 2023 GABROVO

INTERNATIONAL SCIENTIFIC CONFERENCE
17-18 November 2023, GABROVO

INCREASING THE EFFICIENCY OF A SHIP'S AIR-CONDITIONING SYSTEM USING SYNCHRONOUS JET MOTORS

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Abstract

The article presents a study of the replacement of asynchronous electric motors with synchronous jet electric motors and an evaluation of the efficiency of a ship's air conditioning system in energy consumption modes. The balance of passenger ship electricity required to control the climate system for ventilation, cooling and heating is analyzed. The assessment was carried out in terms of fuel oil consumption and CO2 emissions. The partial distribution of the energy of the cooling system and the total consumed energy of the ship are considered. Data from real measurements are presented. The amount of energy saved by the proposal to replace the type of electric motors is calculated.

Keywords: energy efficiency of ships, operational energy efficiency index, ship cooling system, power quality, energy efficiency synchronous jet electric motors.

I. Introduction

The use of seagoing vessels as a means of transport forms about 75% of all external trade of the European Union and up to 31% of the volume of its internal trade. The International Maritime Organization (IMO) has established several levels of emissions into the environment. According to the IMO, NO_x emissions from 2016 should be below 3 g/kWh, and CO_2 emissions should be reduced by 30%. Cruise ships spend a large period of time in port while welcoming their guests or visiting a certain city, where the HVAC system runs constantly and is a major energy consumer throughout the stay. The heating, ventilation and air conditioning (HVAC) system in passenger ships is the second largest energy user after propulsion. Up to 30% of the total energy consumption on a passenger ship comes from HVAC systems. In keeping with energy efficiency, a key concept aboard passenger ships continues to be the heating, ventilation and air conditioning (HVAC) system. This report examines how an HVAC system can be optimized and more energy efficient and provide a comfortable environment for passengers.

II. Calculation of the load and comfort zones of heating, ventilation and air conditioning (HVAC) systems on board passenger ships

In this report, the object of study is a cruise ship with the following parameters: Launched 2008, Gross tonnage 7300GT, Passenger capacity 2500, Maximum capacity 2600, Guest cabins 766, Length[m] 268,Width [m] 33, Number of decks 10, Service speed [kn] 22. The power supply - 6 Wartsila VASA 2200 kW /6.6 kV generators and an emergency generator. The public areas of the ship include two restaurants, shops, as well as a casino, a theater and cinema hall, a disco and a spa center. Electricity consumption in the hotel part (residential premises, common areas and cabins) is supplied by six three-winding substations 6.6 / 0.45 / 0.23 kV., located on different decks. The ship's ventilation system is equipped with five asynchronous motors, which have priority in the power supply and are connected to the main switchboard. Constant air volume ventilation is used on board cruise ships and when the ship is not at full capacity guests may be accommodated in cabins in a single ventilation area. Thus, the ventilation rate and temperature can be reduced in other areas so as to maintain an automated comfort level in the working and living spaces of the ship that would create a human feeling of comfort. For a quantitative assessment of the comfort zone concept, the combined charts of Leisden-Freimark (fig. 1) can be indicated.

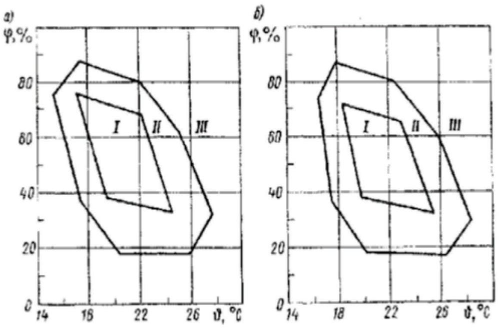

Fig. 1. Comfort zones according to Leisden-Freimark

From Figure 1, we can determine what conditions are pleasant for humans (zone I), acceptable (zone II) and unpleasant (zone III). From the diagrams it can be seen that, together with other parameters, the temperature and relative humidity of the room air are of decisive importance, which should therefore be used as adjustable parameters of the air conditioning system. As a rule, the accuracy of maintaining these values is ±2 to ±0.5°C for the temperature and ±15 to ±5% for the relative air humidity. Sometimes only the above humidity limit is considered sufficient. The analysis provides results that were achieved during the daily operation of the ship and are shown in Table 1. The large cooling peak for the considered cruise which took place in the Caribbean is estimated to be 1.8 MW or 0.75 kW/person. To assess the energy efficiency in the ship's electrical power systems, and in particular the energy efficiency of the air conditioning system, we can use the generalized energy efficiency indicator EEDI (energy efficiency design index) formula 1[1].

$$AttEEDI = \left(MEE + AEE - ERIT\right)\cdot\frac{1}{TW} \quad (1)$$

where: MEE - emissions of CO_2 caused by the main engines [tCO2.DWT]; AEE – CO_2 emissions caused by auxiliary engines [tCO_2.DWT]; ERIT - emission reduction as a result of innovative technologies [tCO_2.DWT]; TW - transport work [DWT]; Calculation of AEE - emissions from (auxiliary engines) is carried out using formula 2:

$$\begin{aligned} AEE = {} & \left(P_{AE}\cdot C_{FAE}\cdot SFC_{AE}\right) + \\ & + \left(\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{n_{PTI}} P_{PTI(i)} - \sum f_{eff(i)} \cdot P_{AEeff(i)}\right) \cdot C_{FAE}\cdot SFC_{AE}\right) \end{aligned} \quad (2)$$

where: P_{AE}[kW] – power of the auxiliary engines, which is theoretically necessary to ensure the operation of the main engines and peripheral equipment, technological equipment and household cargo of the ship; C_{FAE} [t-CO_2/t-Fuel] – coefficient of environmental impact of fuel; SFC_{AE} [t-Fuel/kWh] – specific fuel consumption of the auxiliary engines.

The study period is a four-day cruise, during which the primary energy costs for each typical consumer are accounted for. During this period, it is characteristic that the temperature of the outside air is relatively high, up to 32 degrees, which in turn leads to an increase in the work of the cooling system on board the ship.

Table 2. the cooling coefficient of different types of ships

Ship type	$Q_{O,R/F}$ [KW]	$Q_{O,AC}$ [KW]	$Q_{O,R/F}/Q_{O,AC}$[-]	ΔCOP [%]
Passanger ship	20	1000	0,020	+1,81
Cruise ship	400	12000	0,033	+2,93
Cargo ship	10	150	0,067	+5,49

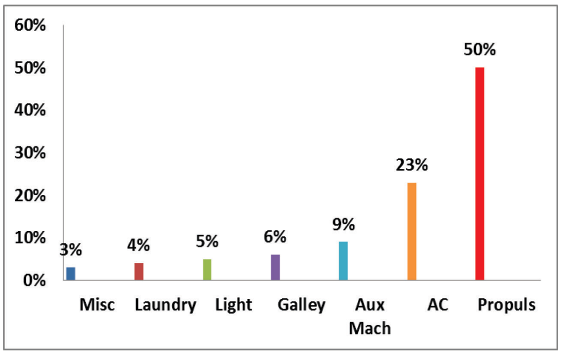

Fig. 2. Energy mix of passenger ship class 1A1

The data were taken from the monitoring system on board a cruise ship, where various values were measured, compiling a database for each day of the cruise shown in Table 2. The actual power consumption of the considered passenger ship type 1A1 is shown in table 2, and the energy mix is shown in fig.2.

Calculation of heat transfer through partitions and decks exposed to the sun is performed according to formula 3.

$$Q = U\ A\ \Delta t \qquad (3)$$

where: U is the overall heat transfer coefficient, A is the area exposed to the sun and Δt is the difference between the temperature of the external surface of the deck and the internal temperature of the heated/cooled zone.

Different ship types have different ratios of cooling to ventilation power. The results of the calculations are presented in Table 2. The power ratio affects the increase in the cooling coefficient provided by the proposed concept (formula 4). The analysis shows a percentage increase in cooling coefficient (ΔCOP) of the combined system compared to the system operating in a separate configuration at a condenser/gas cooler coolant temperature of 36^0C. [3]

$$\Delta COP[\%] = \frac{\Delta COP}{COP_{CSS}}.100\%$$

$$\Delta COP[-] = COP_{CSS,CON} - COP_{CSS} \qquad (4)$$

The power used by the fan located in one cabin on board the ship is calculated by formula 5:

$$\frac{P_{fan}}{P_{(fan\max)}} = \frac{P}{P_{\max}} \qquad (5)$$

where:
- Pfan is the electrical power at which the fan operates [W];
- Pfanmax is the maximum electrical power of the fan [W];
- P is the heating or cooling power used in the fan coil [W];
- Pmax is the maximum heating or cooling power of the fan coil unit [W].

In the different ventilation modes, namely floor ventilation, top ventilation, side ventilation, four independent parameters including temperature, velocity, air stagnation and uniformity index are taken into consideration and applied to evaluate the characteristics of the three ventilation modes.One of the methods for reducing the energy consumption of air conditioning and ventilation systems on board ships by up to 10% is by installing a system to optimize the use of coolers, or the use of a different type of engine. The efficiency of an induction motor is low at low speeds, rotor heat losses reduce its efficiency and power factor. Therefore, a solution is sought by replacing the asynchronous motors with synchronous reactive electric motors, which will provide precise control of energy consumption based on the requirements regarding the ventilation system. With the calculation of the ship's air conditioning system, those parameters and requirements of the electric motors that are observed during operation are determined. The type of ship, its parameters, the sailing area, the number of passengers, the data on the sources emitting heat and moisture serve as the starting data for the calculation of the ship's climate system. For better energy optimization, the optimal ventilation requirements and the number of ventilation zones on board the ship must be established, achieving very important energy savings without any reduction in the performance of the HVAC system.

Table 3. Reported data for the study period

Port Time **(HS. MIN.)**	6h54min	6h24min	3h30min	10h12min	
Maneuvering Time **(HS. MIN.)**	1h48min	0h30min	1h42min	2h18min	
M/E Run. Time by MGO Cons.	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Maneuver.Time Cons. (MEs)	**1,35**	**0,41**	**1,24**	**1,66**	**4,66**
Average Speed	13,80	6,60	7,13	7,16	**8,7**
Distance	211,0	114,0	142,0	82,4	**549,4**
Manuever Distance	11,50	3,05	8,94	15,84	**39,3**
Diesel Gener. HFO Cons.	**22,10**	**20,60**	**21,20**	**20,80**	**84,70**
Diesel Gener. MDO Cons.	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Boiler HFO Cons.	**1,00**	**2,40**	**1,90**	**2,10**	**7,40**
Boiler MDO Cons.	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Boilers In Use	FWD+AFT	FWD+AFT	FWD+AFT	FWD+AFT	
Incinerator MDO consumption	**0,01**	**0,01**	**0,01**	**0,01**	**0,04**
MGO. Emer.Gen. Tenders	**0,00**	**0,00**	**0,50**	**0,00**	**0,50**
S.W. Temperature - C -	**27,0**	**28,0**	**30,0**	**32,0**	
Shaft Power PS (kW)	**75104**	**967**	**17308**	**2898**	**96277,00**
Shaft Power SBS (kW)	**52554**	**38795**	**43182**	**23649**	**158180,00**
Engines in Use	2F	1S	1S	1S	
D/G In Use	PS+CTR	PS+STB	PS+CTR	CTR+STB	
Total KWh	3800	3600	3760	3700	**14860**
A/C Compress. in use	No.1+No.3+No.4	No.1+No4	No.1+No4	No.1+No4	
Compress power I,II (A)	600	620	640	665	
Compress power III,IV (A)	1210	580	600	630	

IV. Ways to optimize operation of the ventilation system

Our solution applicable here is the replacement of asynchronous motors with synchronous reactive electric motors of the manufacturer ABB model 160 M3BL 315SMC 4. Their management is implemented with frequency converters model ACS580-01-363A-4, allowing the management of electric motors with such power. On average, the savings are between 10 – 20% of total energy consumption and the typical payback time is between 2 – 2.5 years. The use of synchronous jet engines that have good efficiency and low energy HVAC system is an integral part of reducing energy consumption and is one of the main objectives to improve ship efficiency. In this way, when replacing the asynchronous electric motors installed on board the ship with ones with the same parameters, but from a new generation, up to 12% electricity savings will be achieved.

ACKNOWLEDGMENT

The scientific research, the results of which are presented in this publication, were carried out under project No. NP17/2023 within the framework of the research activity inherent to the Technical University of Varna, financed on purpose by the state budget of the Republic of Bulgaria.

REFERENCE

[1]RomanianStandardization Association. SR ISO7547, Shipbuilding—Air-Conditioning and Ventilation of Accommodation Spaces on Board Ships—Design Conditions and Basis of Calculations; Romanian Standardization Association: Bucharest, Romania, 2005

[2] Cooling System International Maritime Organization—IMO. SOLAS—International Convention for the Safety of Life at Sea; Lloyd's Register Rulefinder 2020—Version 9.33—Fix; International Maritime Organization: London, UK, 2018.

[3]A. Hafner, C.H. Gabrielii, K. Widell Refrigeration units in marine vessels: Alternatives to HCFCs and high GWP HFCs

[4] Wartzilla 20 product guide. Issue 1/2017.