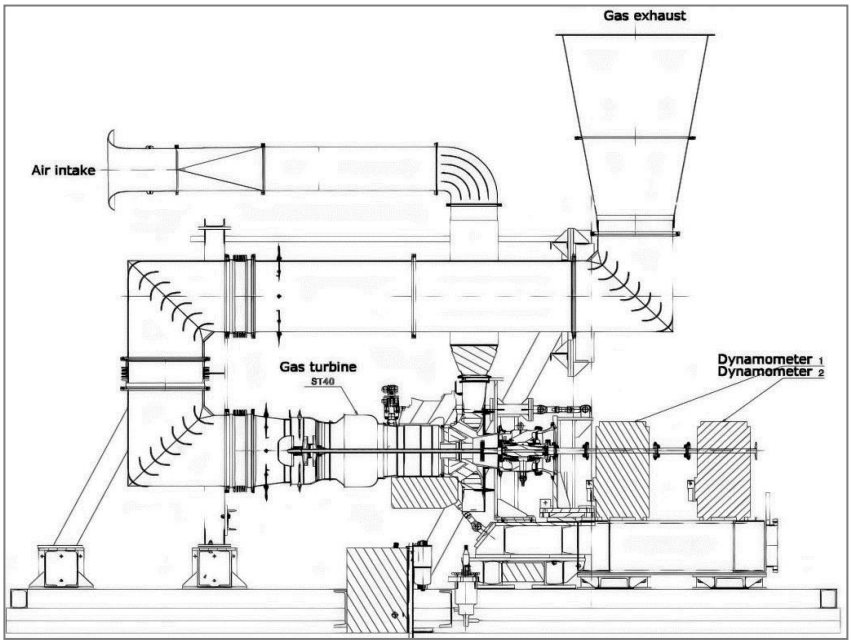

Figure 4. Section through the installation of ST40M gas turbine on test bench

After successful testing, the equipment was transported and installed on the T22 frigate to be revamped, which has two propellers driven by gas turbines in the CoGoG (Combined Gas or Gas) system [12].

As shown in Fig. 6, in the propulsion system of the ship, the ST40M engine replaces the Tyne engine on the port line. After the installation work conducted, tests were carried out to confirm the proper operation of the turbine.

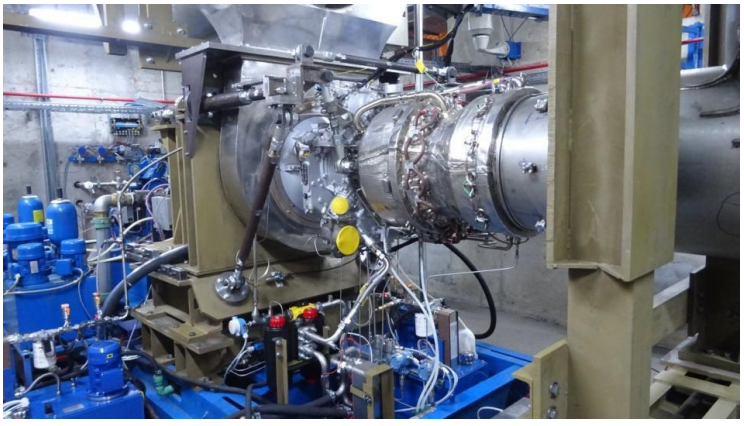

Figure 5. ST40M gas turbine on test bench

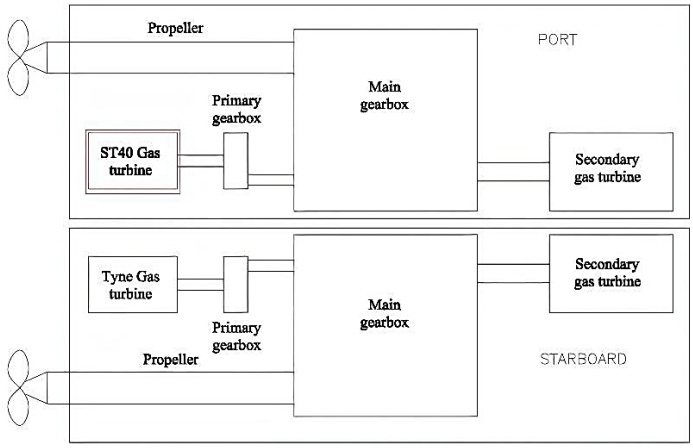

Figure 6. Block diagram regarding ST40M positioning in the test setup on the ship

3. Comparison between the operation of ST40M and Tyne engines

The tests have been performed with the ship in motion, with the naval propulsion group set to operate at regimes between idle and maximum speed. In this way, the turbine load of the propulsion system was achieved by varying the pitch and the propeller speed. Several tests were carried out, including:

- march ahead of the naval propulsion group;
- verification of the ST40 propulsion system acceleration and deceleration;
- endurance tests;
- march forward with ST40M at larboard and towed axle at starboard;
- march ahead and astern.

Figure 7. Tests on the ship with the ST40M engine at port and Tyne engine at starboard

The march ahead with the ST40M engine at port and the Tyne engine at starboard was performed with the two engines in tandem, with the power control levers (PCL) at the same positions, to compare the propulsion characteristics of the ST40M engine with those of the Tyne engine.

The tests were performed in two stages. In the first stage, we obtained the propulsion characteristics of the two engines. Then, the difference between them was corrected by adjustments made to the characteristic of the ST40M engine.

The adjustment consisted in metering the fuel flow to the ST40M engine so that at the command received from the power control lever, at the same positions of the levers the two propulsion lines port and starboard, to develop the same propeller speed.

The results from the first set of tests in Table 1 show that, at the same positions of the power control levers, the fuel flow into the ST40M engine was considerably lower, but the propeller speed was also lower than the one driven with Tyne.

As a result of the corrections of the ST40M engine's characteristics, the two propulsion lines of the ship operate around same parameters (Table 2), for the same positions of the control levers (propeller pitch and propeller speed), which confirm that the two lines have developed the same propulsion power.

Table 1 – **ST40M propulsion without corrections and Tyne characteristics**

Point No.	-	1		2		3		4	
Time	-	11:16		11:34		11:56		12:04	
		ST40	**Tyne**	**ST40**	**Tyne**	**ST40**	**Tyne**	**ST40**	**Tyne**
PCL	div	24	24	40	40	50	50	56	56
Throttle	%	23	20	54	40	76	62	96	78
Fuel flow	l/min	4.8	7.2	7.8	11.9	12.0	17.8	15.4	21.4
Propeller speed	rpm	49	53	70	79	88	99	100	110
Pitch	div	32	32	34	34	34	34	34	34
Ship speed	knot	5.2		9.6		11.8		13.1	

Table 2 – **ST40 propulsion characteristic corrected and Tyne characteristic**

Point No.	-	1		2		3		4	
Time	-	14:19		14:25		14:31		14:41	
		ST40	Tyne	ST40	Tyne	ST40	Tyne	ST40	Tyne
PCL	div	24	28	40	40	50	50	54	54
Throttle	%	6	15	42	38	64	58	76	72
Fuel flow	l/min	5.7	7.6	10.4	11.0	14.8	17.3	17.5	19.9
Propeller speed	rpm	56	54	77	76	97	101	105	108
Pitch	div	32	32	34	34	34	34	34	34
Ship speed	knot	6.0		9.0		11.6		14.1	

From the results shown in Table 2 above, for the positions of the control levers, the consumption of the propulsion system with ST40M is lower with ~12% than with Tyne engine. Therefore, at the revamp of the T22 frigate, which will suppose replacing both Tyne engines for cruise speed, a fuel saving of almost a quarter shall be obtained. Even though the fuel flow is lower, the propellers speed values are very close, which demonstrate the increased efficiency of ST40M.

6. Conclusions

The replacement of the outdated Tyne gas turbine, whose production and service have been terminated, with the newer ST40M gas turbine is economically justified. Besides the maintenance that can be ensured due to the ongoing manufacturing of its component parts, the ST40M turbine is also noted for its lower weight and lower fuel consumption at the same developed power.

The results obtained by replacing the turbines on the ship during sea tests have been presented. After conducting a first set of tests aiming to find the adjustments and corrections that had to be made, the second set of tests with the engines running on the ship's propulsion lines have shown the increased efficiency of the newer ST40M turbine.

From tests conducted with the frigate in motion, substantial fuel savings can be forecasted, along with the reduction of the carbon dioxide and monoxide emissions and of other secondary products resulted from the fuel combustion process, which are environmentally harmful.

Future research will consider revamping the T22 frigate by replacing both Tyne engines, and assessing the parameters of ST40M gas turbines during normal operation. As well, the efficiency increase of the new propulsion system comparing to the old engines will be observed. The fuel reduction and the carbon dioxide emissions shall also be measured, highlighting the reduction percentage.

ACKNOWLEDGEMENT

The work presented herein was funded by the Operational Programme Human Capital of the Ministry of European Funds through the Financial Agreement 51675/09.07.2019, SMIS code 125125.

R E F E R E N C E S

[1] *Y. G. Li and P. Nilkitsaranont*, "Gas Turbine Performance Prognostic for Condition-Based Maintenance", *Applied Energy* 86, no. 10 (2009): pp. 2152-2161. DOI: 10.1016/j.apenergy.2009.02.011.

[2] *Piotr Laskowski*, "Damages to Turbine Engine Components", *Scientific Journal of Silesian University of Technology. Series Transport* 94 (2017): pp. 111-121. DOI: 10.20858/sjsutst.2017.94.11.
[3] *** "ST40M-Marine and Industrial Gas turbine"-Fact sheet, Pratt & Whitney Canada.
[4] *** "P&W to Power Norwegian Navy "Skjold" Patrol Boats", Defense-Aerospace.Com, 2019, http://www.defense-aerospace.com/articles-view/release/3/32064/ p%26w-turbines-for-%E2
[5] %80 %98skjold%E2%80%99-boats-(jan.-20).html.
[6] *** "Rolls-Royce Engines: Tyne - Graces Guide", Gracesguide.Co.Uk, 2019, https://www.gracesguide.co.uk/Rolls-Royce_Engines:_Tyne.
[7] *H. Kayadelen, Y. Ust*, "Thermodynamic Properties of Engine Exhaust Gas for Different Kind of Fuels", Lecture Notes in Electrical Engineering 307, pp. 247-259, 2014. DOI: 10.1007/978-3-319-03967-1_19.
[8] *M. Elgohary, I. Seddiek*, "Comparison between Natural Gas and Diesel Fuel Oil Onboard Gas Turbine Powered Ships", Journal of King Abdulaziz University, vol. 23, no. 2, pp. 109-127, 2012. DOI: 10.4197/mar.23-2.7.
[9] *F. Niculescu, C. Borzea, A. Savescu, A. Mitru and M. Vasile*, "Automation and Electronic Control of Marine Gas Turbine Engine for Ship Revamp", *Technium*, vol. 2, no. 4, pp. pp. 98-108, 2020. ISSN: 2668-778X.
[10] *B. MacIsaac, R. Langton*, "Marine Propulsion Systems", *Gas Turbine Propulsion Systems*, 2011, 195-225. DOI: 10.1002/9781119975489.ch9.
[11] *G. Samoilescu, D. Iorgulescu, R. Mitrea, L. D. Cizer*, "Propulsion Systems in Marine Navigation", *International Conference KNOWLEDGE-BASED ORGANIZATION*, Vol. 24, no. 3 (2018): pp. 78-82. DOI: 10.1515/kbo-2018-0140.
[12] *C. G. Hodge*, "The Integration of Electrical Marine Propulsion Systems", *International Conference on Power Electronics Machines and Drives*, 2002. DOI: 10.1049/cp:20020081.
[13] *F. Niculescu, M. L. Vasile, C. Nechifor, A. Stoicescu*, "Comparative Analysis between Gas Turbine and Electric Combined Propulsion", EV2019 - ELECTRICAL VEHICLE INTERNATIONAL CONFERENCE & SHOW", Bucharest, October 3-4, 2019. DOI: 10.1109/EV.2019.8893015.