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# Ring thruster – a preliminary optimisation study

**Leszek Matuszewski**, Ph.D.
Gdansk University of Technology

ABSTRACT

*The ring thruster is a new type of propeller, for which there is no experimental data to verify analytical design calculations. A significant feature of the ring thruster is the absence of a shaft. Propeller blades are mounted to the ring rotating inside the housing, which has the shape of a nozzle. For this reason the ring thruster is closest, with respect to both the construction and principle of operation, to the Kort nozzle propeller. The absence of a shaft and no gap between the blades and the nozzle make it impossible to fully relay on results obtained from Kort nozzle propeller examination. What is more, the already existing computer codes developed for designing Kort nozzle propellers cannot be directly used for designing ring thrusters either. That is why for this purpose a new code determining hydrodynamic characteristics based on the theory of the vortex lifting surface will be used. When using the above method, some differences between calculated and experimentally recorded results are expected to be observed. To a significant extent, the level of the torque taken by the thruster will be affected by drag of the rotating ring to which the blades are fixed. Examining a propeller equipped with a rotating ring has revealed that the expected torque increment may reach as much as a few per cent, at the comparable level of axial force (thrust). At the present stage of ring propeller investigations there is no data available on how to shape the ring propeller blades. Possible comparison calculations, done using the existing computer code, will allow, the most, the shape of the blades to be determined for preliminary tests in the cavitation tunnel and on a self-propelled model. And only the results obtained in these tests will provide opportunities for verification of preliminary design calculations. It should be stressed, however, that developing design procedures for this type of propellers will require additional optimisation calculations, with further experimental verification. And this should be the subject of separate investigations.*

**Key words**: hydrodynamics, marine engine, thruster

## GOAL AND SCOPE OF EXAMINATION

The goal of the reported activities was to perform preliminary hydrodynamic tests of the prototype ring thruster delivered by the employer. The main dimensions of the examined thruster were the following :

- ✶ outer ring diameter Dzd = 0.208 m
- ✶ inner diameter of ring motor Dw = 0.130 m
- ✶ width of housing (nozzle) B = 0.1365 m
- ✶ number of blades z = 6

The scope of the examination includes measurement of the axial force induced by the ring thruster at different propeller revolutions and different velocities of the water approaching the thruster.

A tensometric dynamometer JK-21-2-500N-2003 IMP PAN allows total thrust force of the Tpx unit to be measured. This force comprises the thrust generated by the propeller and the nozzle, and the drag generated by the elements connecting the thruster with the dynamometer (connectors and a cable).

The torque is determined from the power calculated based on measurements of parameters of the electric current supplying the rotor, and therefore it can be burdened with some error.

## RESEARCH RIG

The research rig, which is the cavitation tunnel K11-MH IMP PAN, was prepared for examining the new generation ring thruster (a general view of the rig is shown in Photo 1).

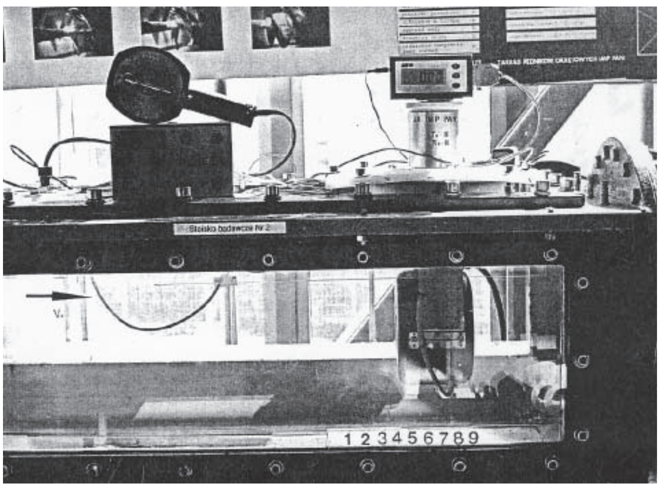

***Photo 1.*** *Research rig for ring thruster examination*

A prototype strain-gauge dynamometer JK-21-500N-2003 IMP PAN, mounted with relevant accessories and fixing system, is shown in Photo 3.

The system for measuring, storing and processing of changing forces Tpx and Rox makes use of a microprocessor measuring amplifier AWO 100, linked with the computer via RS 232C interface.

The average velocity in the measuring section of the cavitation tunnel was determined from the pressure difference measured in the tunnel confusor using a liquid-column gauge.

The propulsion system of the ring thruster consists of the nozzle-shaped housing and the internal ring with six blades fixed to it, (Photo 2).

Revolutions of the propulsion motor were controlled using a programmable inverter.

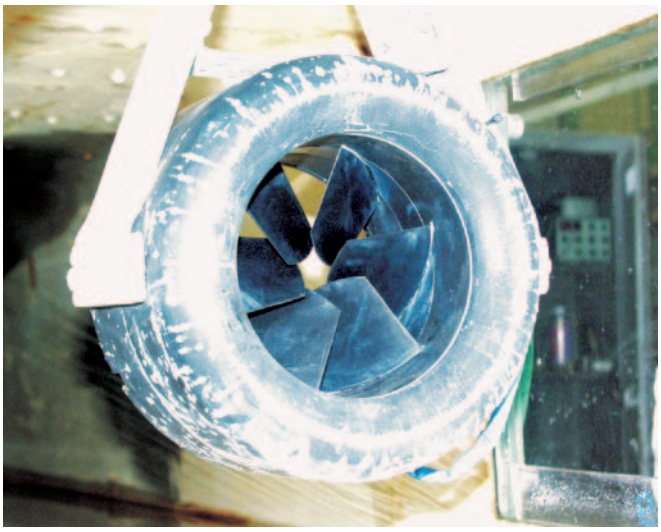

***Photo 2.** Ring thruster installed in the cavitation tunnel*

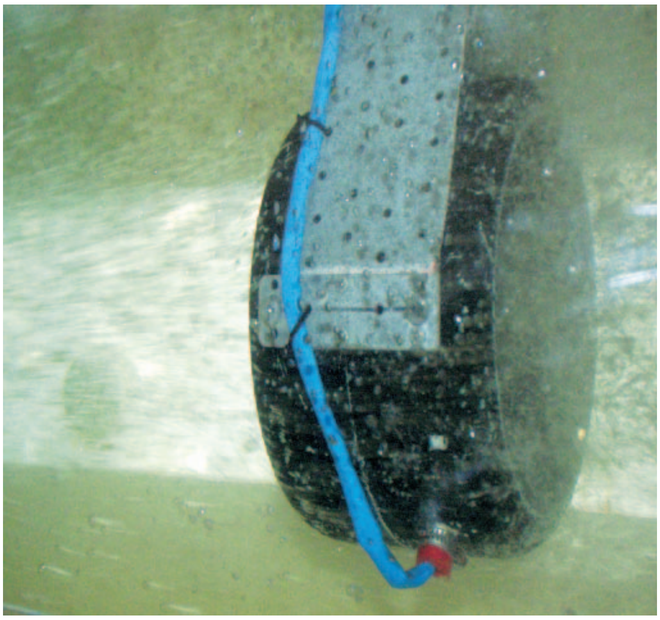

***Photo 3.** Ring thruster in operation*

## EXAMINATION PROCEDURES

The substitute ring thruster (Dw = 0.13 m) delivered by the employer was mounted in a strain-gauge dynamometer JK-21-2-500N-2003 IMP PAN, especially manufactured for this purpose, and then installed on the properly instrumented research rig No. 2 (Cavitation Tunnel, type K11-MH) in the Szewalski Institute of Fluid-Flow Machinery PAS, Gdansk.

Ring thruster examination included the following tests:

- ✦ drag generated by a dummy ring thruster at different water velocities
- ✦ mechanical drag generated by the ring thruster in the air for different propeller revolutions
- ✦ ring thruster examination for different water velocities and different rotational speeds of the propeller.

During the examination the following quantities were recorded:

- Propeller revolutions **n** [rev/min]
- Speed of water in tunnel measuring section **V** [m/s]
- Total thrust and drag generated by ring thruster **Tp**x [N]
- Drag generated by dummy ring thruster, console, and cable **Ro** [N]
- Total torque taken by thruster **Q** [Nm]
- Internal ring thruster drag torque in air **Qo** [Nm]
- Other recorded quantities included electric current intensity and voltage generated by the inverter supply system in the ring thruster motor.

The examination was performed for steady water velocities and changing ring propeller revolutions.

The examination was divided into test series, and the results of measurements were stored in the computer, in files named for instance „1200-01.dat" which means the first test series at revolutions 1200 rev/ min.

Instantaneous torque values were stored in computer's memory and then averaged, while the thrust generated by the thruster were averaged in the microprocessor based measuring instrument, by introducing a filter. The averaged results were then presented on a digital display.

***Photo 4.** Research rig during ring thruster examination*

## RESULTS OF EXAMINATION

The tables below collect selected results of measurements, recorded on the research rig in the cavitation tunnel with the ring thruster. These results are grouped in properly numbered series.

Quantities mentioned in the tables :

Water velocity at the entrance to the measuring section is given in mm water column Δh. Real velocity is determined from the relation:

- ⇨ $V = 0.1412 \sqrt{\Delta h}$ [m/s]
- ⇨ total thrust (measured) Tpx generated by the entire set is given in [kG]
- ⇨ torque is given in [kGm]
- ⇨ revolutions are given in [ rev/min].

*Tab. 1. Results of ring thruster examination*

| File | n [rev/min] | Tpx [kG] | Δh [mm] | Q [kGm] | No. of series |
|---|---|---|---|---|---|
| 1200-01.dat. | 1200 | 11.4 | 15 | | 1 |
| 1000-01.dat. | 1000 | 7.75 | 10 | | 1 |
| 1200-01.dat. | 1200 | 11.32 | 11.32 | | 1 |
| 800-01.dat. | 800 | 4.96 | 6 | | 1 |
| 700-01.dat. | 700 | 3.76 | 5 | | 1 |
| 1250-01.dat. | 1250 | 12.35 | 16 | | 1 |
| | | | | | |
| 1100-02.dat. | 1100 | 8.0 | 35 | | 2 |
| 1000-02.dat. | 1000 | 6.32 | 30 | | 2 |
| 800-02.dat. | 800 | 3.35 | 30 | | 2 |
| 700-02.dat. | 700 | 2.26 | 30 | | 2 |
| 1200-02.dat. | 1200 | 9.2 | 40 | | 2 |
| 1000-02.dat. | 1000 | 5.91 | 40 | | 2 |
| 1200-02.dat. | 1200 | 9.2 | 40 | | 2 |
| | | | | | |
| 1300-03.dat. | 1300 | 7.8 | 76 | | 3 |
| 1200-03.dat. | 1200 | 6.57 | 90 | | 3 |
| 1000-03.dat. | 1000 | 3.37 | 86 | | 3 |
| 800-03.dat. | 800 | 0.9 | 82 | | 3 |
| 700-03.dat. | 700 | -0.14 | 80 | | 3 |
| | | | | | |
| 1300-04.dat. | 1300 | 3.22 | 200 | | 4 |
| 1200-04.dat. | 1200 | -1.62 | 196 | | 4 |
| 1000-04.dat. | 1000 | -1.3 | 190 | | 4 |
| | | | | | |
| 1400-05.dat. | 1400 | 15.2 | 20 | | 5 |
| 1300-05.dat. | 1300 | 13.1 | 18 | | 5 |
| 1200-05.dat. | 1200 | 11.1 | 16 | | 5 |
| 1000-05.dat. | 1000 | 7.76 | 10 | | 5 |
| 800-05.dat. | 800 | 4.88 | 6 | | 5 |
| | | | | | |
| 800-06.dat. | 600 | -0.8 | 85 | 0.24 | 6 |
| 1000-06.dat. | 1000 | 3.26 | 87 | 0.5 | 6 |
| 1200-06.dat. | 1200 | 6.33 | 93 | 0.6 | 6 |
| 1300-06.dat. | 1300 | 8.1 | 96 | 0.75 | 6 |
| 1400-06.dat. | 1400 | 10.12 | 100 | 1.0 | |
| | | | | | |
| 1400-07.dat. | 1400 | 5.16 | 205 | 0.9 | 7 |
| 1300-07.dat. | 1300 | 3.19 | 204 | 0.65 | 7 |
| 1200-07.dat. | 1200 | 1.47 | 202 | 0.5 | 7 |
| 1000-07.dat. | 1000 | 1.44 | 198 | 0.3 | 7 |
| 800-07.dat. | 800 | -3.71 | 195 | | 7 |
| 1500-07.dat. | 1500 | 6.91 | 215 | | 7 |
| | | | | | |
| 1450-08.dat. | 1450 | 16.74 | 24 | | 8 |
| 1400-08.dat. | 1400 | 15.32 | 20 | 1.0 | 8 |
| 1300-08.dat. | 1300 | 13.13 | 18 | 0.7 | 8 |
| 1200-08.dat. | 1200 | 11.2 | 16 | 0.6 | 8 |
| 1000-08.dat. | 1000 | 7.74 | 10 | 0.4 | 8 |
| 800-08.dat. | 800 | 4.96 | 6 | | 8 |
| 1477-08.dat. | 1477 | 16.9 | 24 | 0.9 | 8 |

*Tab. 2. Torque generated by ring thruster working in air $Q_0$*

| Series | n [rev/min] | $Q_0$ [kGm |
|---|---|---|
| MOM 1400 | 1400 | 0.15 |
| MOM 1200 | 1200 | 0.125 |
| MOM 800 | 800 | 0.085 |

The results of measurements, obtained after doing relevant recalculations to dimensionless coefficients of thrust, $K_T$, and torque, $K_Q$, are given in Figs 1 and 2.

Fig. 1 shows the results of measurements of thrust (axial force) induced by the entire ring thruster, in the arrangement: dimensionless thrust coefficient $K_T$ vs. advance coefficient J.

Fig. 2 presents the results of measurements of the torque taken by the ring thruster, in the similar arrangement: dimensionless torque coefficient $K_Q$ vs. advance coefficient J. The dimensionless coefficients are defined as:

$$K_T = T/(\rho n^2 D^4)$$
$$K_Q = Q/(\rho n^2 D^5)$$
$$J = V/(nD)$$

Figs 1 and 2 show two curves, of which the broken curve refers to the thruster working in water. The continuous curve was obtained by deducting torque $Q_0$, representing internal drag, from the total torque Q.

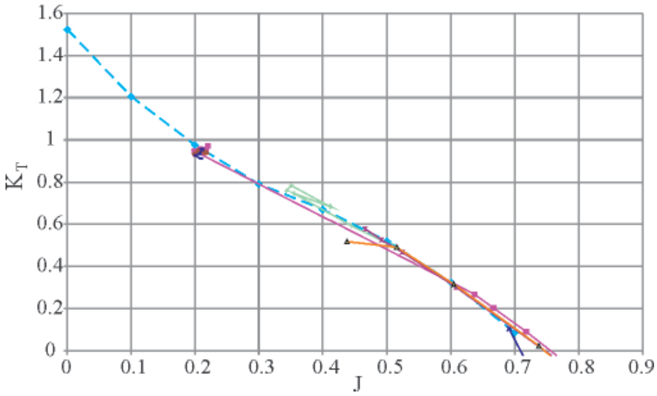


*Fig. 1. Results of calculations of thrust coefficient $K_T$ induced by the entire thruster*

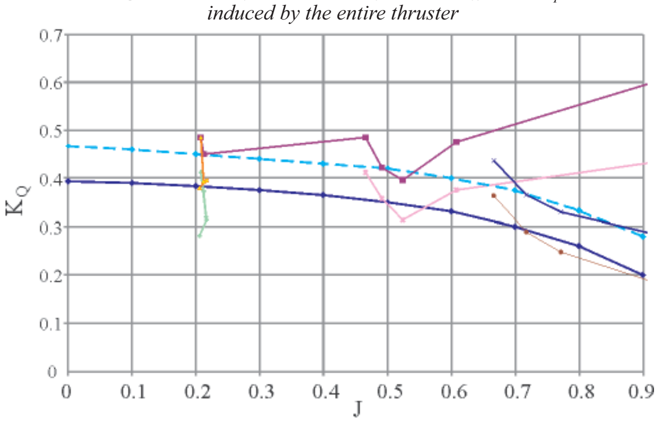


*Fig. 2. Results of calculations of torque coefficient $K_Q$*

The scope of measurements included thruster operation above J = 0.2 (measuring points are shown in the figures). For J lower than 0.2, including J = 0, the curves were extrapolated using the analogy to other Kort nozzle examinations. Using the same analogy the thrust induced by the entire thruster was hypothetically divided into part induced by propeller blades and that induced on the nozzle (ring). The proposed division is shown in Fig. 3.

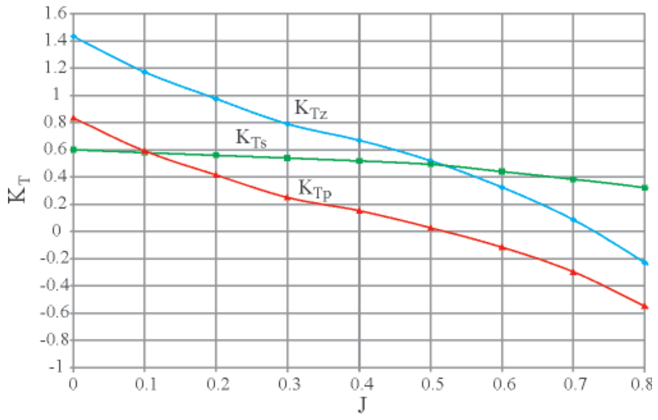


***Fig. 3.*** *Approximate division of total thrust $K_{Tz}$ into part $K_T$ induced by thruster blades and part $K_{Tp}$ induced by the surrounding ring (nozzle)*

The presented results should be treated as concerning preliminary investigations of this type of propellers in Poland. Very interesting results were obtained for total thrust and torque induced by the entire thruster. Diagrams in Figs 1 and 2 deliver a lot of new information on the performance of these types of propellers, but at the same time new problems can be addressed which need solving.

What needs clarifying first is why the measured torque, induced on the blades and the ring, differs so dramatically (more than twice) from the calculated value of the torque induced by the blades alone. It would mean that the torque induced on the ring is very high and considerably affects thruster's performance. If so, its reduction is a priority for improving thruster's performance.

It would also mean that the substitute seal and bearings of the examined thruster do not fulfil requirements concerning the minimisation of drag forces generated by the ring moving in the gap.

In this type of investigations, good preparation and execution of measurement of a torque attributed to viscous losses on the ring, irrelevant of the torque induced by the blades, is the high priority.

The analysis of thrust examination results (table 1) reveals that the ring surrounding the propeller has favourably affected the total thrust. Fig. 3 shows a diagram with hypothetical division of the total thrust $K_{Tz}$ into part $K_{Ts}$ induced by the blades and part $K_{Tp}$ induced by the ring.

The curve $K_{Ts}$ was created using as a basis the point calculated for the blades alone and assuming the analogy to the Kort nozzle propeller examination. The shape of the curves is realistic, but it should be confirmed (or verified) by relevant examination of a propeller driven in a way classical for the Kort nozzle propeller system.

## CONCLUSIONS

- To sum up, from the point of view of hydromechanics, independently of definite design solutions (including the motor, bearings, lubrication, seals) worked out for the presented propulsion system, more comprehensive model investigations should be carried out to determine relevant empirical corrections which would allow these propellers to be designed in a way similar to that followed when designing Kort nozzle propellers.
- High efficiency and dynamics of electric drive systems used on watercraft resulted in their increased proportion in total number of drive applications. Thanks to the development of mechatronics, electrotechnics and hydrodynamics, the time has come when earlier solutions in this area can be put in practice. Among water propulsion systems, especially attractive properties are represented by ring-type propellers, but only equipped with electromagnetic bearings. A characteristic feature of the motor, being an extension of a classical synchronous motor with permanent magnets, is that the ring with propeller blades is a part of the rotor. Dimensions of the nozzle in which the winding is mounted do not exceed dimensions resulting from the optimum geometry of the Kort nozzle propeller for the assumed power. As recently as a few years ago the development in the field of magnetic materials, ferrofluid liquids, non-linear control techniques and hydrodynamics reached a level providing opportunities for effective introduction of ring-type propulsion systems on a large scale. A drive which is expected to be especially promising in the nearest future is the ring thruster, used as a manoeuvring drive, and the main drive on smaller watercraft. The experience gained in designing ring thrusters with magnetic bearings has provides opportunities for manufacturing an efficiently working prototype and offering it on the market of water propulsion systems.
- Ring propulsion systems with classical bearings are slowly becoming more and more popular, but still their efficiency is lower than 20% due to relatively high drag. A quantitative break-through in the field of efficiency improvement can be only secured by the use of magnetic bearings.
- An additional advantage of the ring thruster is its ability to switch to turbine operation, in which it can be used as electric power generator. In numerous situations this property makes it possible to recover energy.

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**CONTACT WITH THE AUTHOR**


Leszek Matuszewski, Ph. D.
Faculty of Ocean Engineering
and Ship Technology
Gdansk University of Technology
Narutowicza 11/12
80-952 Gdansk, POLAND
e-mail: leszekma@pg.gda.pl