International Journal of Multidisciplinary and Current Research ISSN: 2321-3124
Research Article Available at: http://ijmcr.com

The Effect of changing the Propeller Systems on the Measured Bollard pull

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Received 21 Dec 2022, Accepted 01 Jan 2023, Available online 02 Jan 2023, **Vol.11 (Jan/Feb 2023 issue)**

Abstract

The bollard pull is very important for the safety of the tug boat operation. The different propeller systems have a significant effect on the measured thrust. Using different propeller models with different systems in experimental test rig the bollard pull measured and compared and the results are analyzed to find the effect on the measured bollard pull

Keywords: *Bollard Pull, Propeller Dimensions, Exerted Thrust, Test rig, Ducted propeller, thrust coefficient.*

1. Introduction

1.1 Bollard pull

Bollard pull is the tractive force of a tug boat expressed in tons or kilo Newton it describes the pulling capability of the tug. It is defined as the mean exerted force at zero speed for a certain period of time.

The bollard pull is really important as it is used to obtain the pre-planned towing-speed.

It provides sufficient power-reserve to ensure safety of the tow also in unfavorable current- and weather conditions.

1.2 Factors Affecting the Bollard Pull

The following factors are directly related to tug's generated BP [1].

- Tug's engine output expressed in BHP
- Maximum Continuous Rating.
- Propeller type and size.
- duct.
- Shape of the hulls submerged part.
- Draught.
- Trim.
- Max.Wind
- Max. Waves
- Max. Current

1.3 Bollard pull test

Bollard Pull test is carried out by steaming into a towrope which is fixed ashore and connected to a measuring device, successively with three different performance-level

- Part load (80%),
- Full load (100%),
- Overload (110%) [2].

1.4 The effect of propeller system and design on the measured bollard pull

The propeller types and dimension have a significant influence on the measured bollard pull. The propeller geometrical data and different propeller designs have a significant effect on the measured bollard pull and the thrust coefficient. Such as blade area ratio, propeller diameter, number of blades, opened propeller or ducted propellers.

1.5 Bollard Pull Trials

To determine the maximum static thrust for the tug boats, the bollard pull trails are carried as follows:

a- Maximum bollard pull for 1 min- at max input of ship's engine power.
b- Steady BP over a period of 5 min.
C-Effective BP in open water conditions, this usually approximated to 78% of the steady bollard pull due to the weather conditions [3].

For costal tugs the typical BP is in range of 15- 30 tons.
For ocean tugs the typical BP is in range of 30- 110 tons.

2. Experimental setup

To study the effect of changing the propeller systems on the static thrust, an experimental test rig was used to measure the bollard pull and the thrust coefficient.

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DOI: https://doi.org/10.14741/ijmcr/v.11.1.4

A test rig equipped with motor driven and motor inverter is manufactured.

Using a load cell and scale meter the bollard pull measured and the thrust coefficient was calculated. A propeller model is used with different geometrical data and different propeller systems as using fixed pitch propeller, variable blade angle propeller, and ducted propeller. Experimental results are provided shows the effect of the number of blades as well on the measured bollard pull and thrust coefficient.

The tests are carried in media of air in the laboratory

2.1 propeller models

A fixed pitch propeller model plastic made is used as shown in fig (1.0) and the data showed in table (1.1)

Figure 2.1 Fixed pitch propeller model (E)

Table 2.1 Propeller model (E) data

No. of blades(Z)	4
Disc area (A)	0.1256 m^2
Nominal pitch (P)	0.203 m
Diameter (D)	0.4m
Blade area (BA)	0.0952 m^2
Blade area ratio (BAR)	0.7579
Pitch diameter ratio (p/d)	0.507

A Special aluminum hub had been designed with a number of four holes each at 90^0 for fitting the four blades and fastened to the hub by using necessary bolt. Which enable to change the number of blades and the blades angles as shown in fig (2.3).

The propeller blades were fitted to designed hub in such way to allow the adjustment of blade angle direction as shown in fig (2.2).

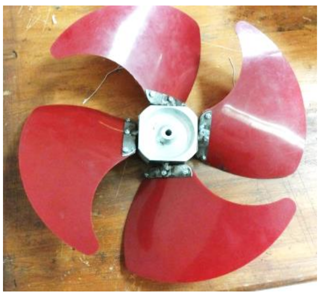

Figure 2.2 Variable blade angle propeller model (F)

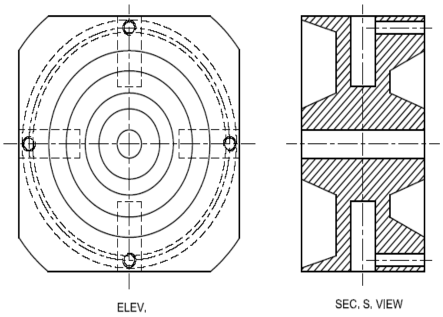

Figure 2.3 Designed hub

Figure 2.4 Blade angles

Figure 2.5 2 blades propeller

2.5 Duct design

An open Duct has been designed from galvanized steel of 0.8 mm thickness with a taper of 8^o . The duct length is 0.2m; the duct is fitted on the carriage around the propeller with clearance of 1cm. The duct weight found to be 2.08 kg. The manufactured duct is shown in fig (2.6).

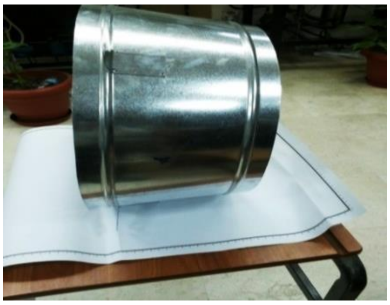

Figure 2.6 Designed duct

2.3 Test rig

A test rig used for tests as shown in fig (2.7) consists of shafting arrangement from aluminum the propeller model fitted on the shaft end and is driven by an electric motor coupled to the other end which fitted to the load cell against a barrier fitted in the chaises. All are set on carriage equipped with four Teflon wheels which are set on two aluminum bars to reduce the friction.

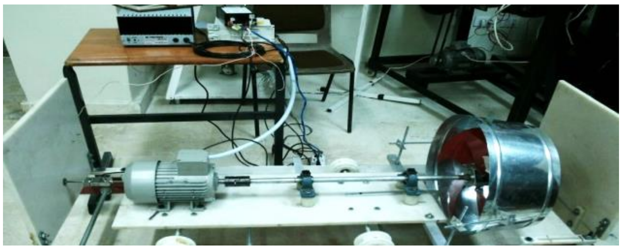

Figure 2.7 Test rig

2.3.1 Frequency Inverter

The used frequency inverter is manufactured by ABB. Its model number is ACS 150. The said device is shown in fig (2.8). It is equipped with a display screen and a speed controller for the motor. The Voltage range is from 200 to 240 volts, 50 cycles.

The inverter is used to control the motor rotational speed at the measured thrust. Motor speed was changed at interval of 100 R.P.M then the propeller thrust is measured at a particular speed.

Figure 2.8 ABB Frequency Inverter, (Model number ACS 150)

2.3.2 Load Cell Specifications

The load cell is manufactured by Omega Engineering. Its type is stainless steel "S" beam and its model number is LSM101-25, as displayed in fig (2.9). It requires a 10-volt DC supply and its temperature range is from 17 to 71 Celsius. Its capacity ranges from 0.000 to 25 kg_f.

Figure 2.9 Omega's LCM101-25 Load Cell

2.3.3 Scale Meter

The scale meter is manufactured by Omega, with model number DP41-W. Its input ranges from -50 V to 100 V dc and 4-20 mA dc. It uses a dual slope conversion technique consuming from 3 to 9 Watts maximum. It's operating temperature range from 0 to 50 degrees Celsius. A snapshot of the device is shown in fig (2.10).

Figure 2.10 Omega's DP41-W Scale Meter

2.3.4 Load Cell and Scale Meter Calibration

Different weights were applied to the load cell and the corresponded reading indicated by the scale meter was recorded. The result of the calibration process are shown in table 2.3and graphically presented in fig. (2.11).

Table 2.3 Load Cell Scale Meter Calibration

Weight (kg)	Reading
0.0	474
0.144	694
0.597	1354
1.0505	2019
1.5035	2684
1.957	3349
2.410	4024
2.866	4689
3.3195	5359
3.7725	6029
4.226	6699
4.679	7374
5.135	8039
5.5885	8720
6.495	10064
6.951	10780

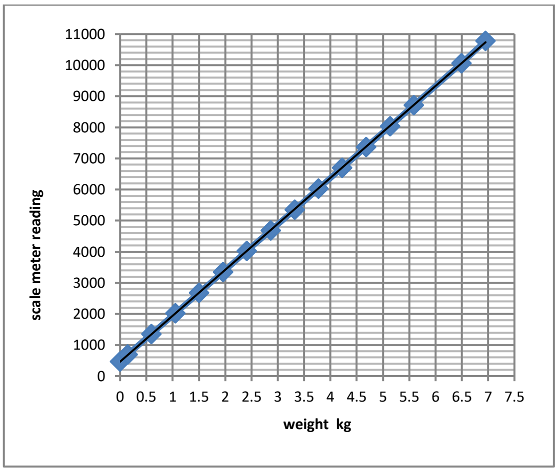

Figure 2.11 Scale Meter Reading and Corresponding Force

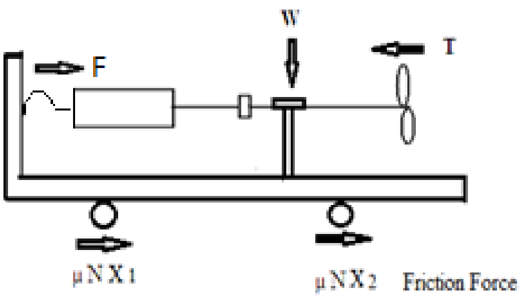

Figure 2.12 Test rig force analysis

3. Tests and results

The load cell is fixed between the motor and the barrier and connected to the scale meter; a 10 volt DC was obtained from an external power supply.

From figure (2.12) the thrust can be calculated as follows: For equilibrium position,

$\sum F_y = 0$

$W = N_1 + N_2$ (2.1)

$\sum F_x = 0$

$T = \mu.N_1 + \mu.N_2 + \boldsymbol{F}$ (2.2)

$T = \mu(N_1 + N_2) + \boldsymbol{F}$

$T = \mu W + \boldsymbol{F}$ (2.3)

W is the weight of the test rig and propeller arrangements, μ is coefficient of friction between Teflon and aluminum = 0.19**[4]**, ***F*** is the measured force by scale meter

The thrust is calculated from the equation: T=μ.N + ***F*** (*) (2.4)

The thrust force (*T*), is expressed in dimensionless from, with the help of the thrust coefficient *KT,* as follows:

$KT = \frac{T}{\rho \times n^2 \times D^4}$ [5].

ρ is the air density ,*n* is r.p.s, and *D* is the propeller diameter.

Reynods's number can be calculated from the formula $R_e = \frac{\rho n D^2}{\mu}$ [5] , μ is the air kinematic viscosity.

3.1 Variable Blade Angle Tests

Blade angle is the angle between the blade and the axis on the hub. The blade angle can be changed in 10° as shown fig. (2.4).

Tests were carried to Propeller model (F) and for different blade setting angles of 20°,30° and

The exerted thrusts are calculated at different rpm the results are plotted in fig (3.1)., the effect of blade angles on the propeller thrust coefficient shown in fig (3.2)

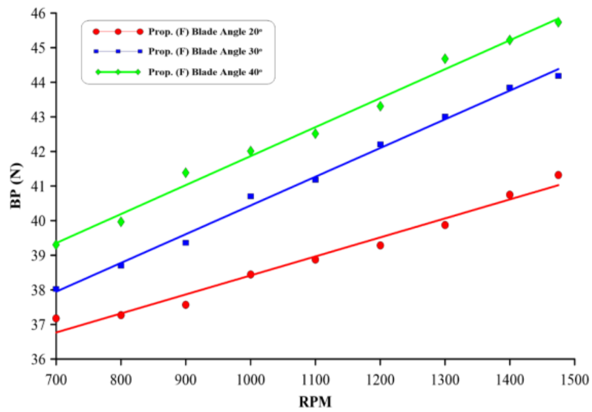

Figure 3.1 the effect of blade angle on the measure bollard pull

Table 3.1 Percentage of Bollard Pull for different Blade angles

RPM	BP at blade angle 20°	BP at blade angle 30°	% increase than 20°	BP at blade angle 40°	% increase than 20°
700	37.174	38.027	2.29	39.30278	5.72
800	37.272	38.694	3.81	39.9698	7.23
900	37.566	39.361	4.77	41.3825	10.15
1475	41.323	44.188	6.933	45.7381	10.68

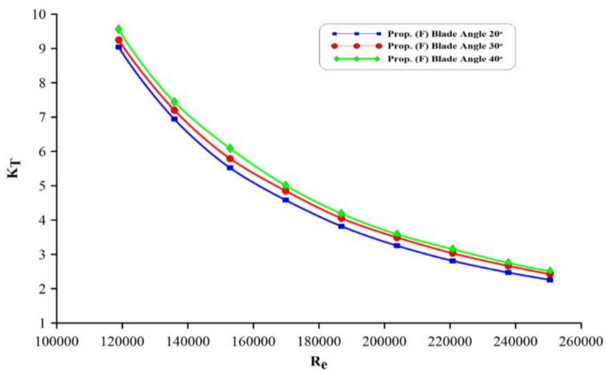

Figure 3.2 The effect of blade angles on the thrust coefficient

Table 3.2 Percentage of Change in Thrust Coefficient for Different Blade Angles

Re	K_T at blade angle 20°	K_T at blade angle 30°	% of increase than 20°	K_T at blade angle 40°	% of increase than30°
118895.96	9.04	9.248	2.3%	9.558	3.35%
135881.10	6.94	7.205	3.82%	7.442	3.3295
152866.24	5.52	5.791	4.90%	6.088	5.128%
250530.78	2.26	2.4204	7.09%	2.505	3.507%

3.1.1 Effect of blade Angle and Pitch on the measured Bollard Pull and Thrust Coefficient

There is an increase in the measured thrust as blade angle increased and pitch increase as shown in table (3.1).

By increasing the blade angle from 20^0 to 30^0 and to 40^0 at the same rpm, where the percentage of increase bollard pull measured at blade angle 40^0 is nearly doubled than measured at $30^{0.}$ As shown in fig (3.2) and table (3.2) as the blade angle increased the thrust coefficient increase at the same Reynolds's number.

3.2 Effect of number of blades tests

The test is carried for the propeller model (F) of 2 blades and 4 blades at different blade angles 10°, 20°,30° and 40°·as shown in the following figures.

3.2.1 Effect of number of blades on the measured thrust

As shown in fig (3.3) the thrust is larger of 4 blades propeller than the 2 blades propeller at blade angle 10^0 the percentage of increase is between 0.26 and 1.10 % at 1400 and 500 rpm respectively.

As shown in fig (3.4) the thrust is larger of 4 blades propeller than the 2 blades propeller at blade angle 20^0 the percentage of increase is between 1.203 and 2.44 % at 300 and 1475 rpm respectively.

As shown in fig (3.5), the thrust is larger of 4 blades propeller than the 2 blades propeller at blade angle 30^0 the percentage of increase is between 0.024 and 3.86% at 200 and 1475rpm respectively

As shown in fig (3.6) the thrust is larger of 4 blades propeller than the 2 blades propeller at blade angle 40^0 the percentage of increase is between 0.268and 3.773% at 300- and 1475rpm respectively.

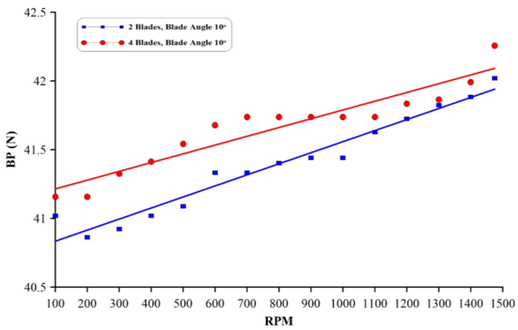

Figure 3.3 Effect of Number of Blades on Bollard Pull - Blade Angle 10^0

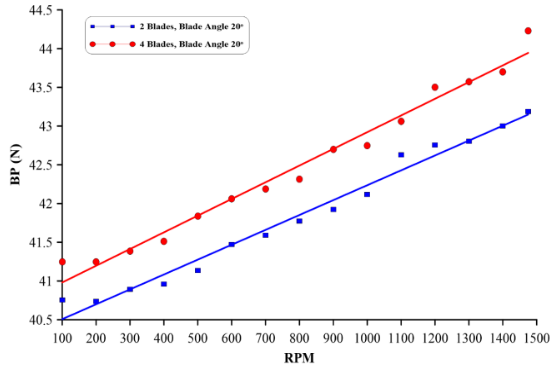

Figure 3.4 Effect of Number of Blades on Bollard Pull - Blade Angle 20^O

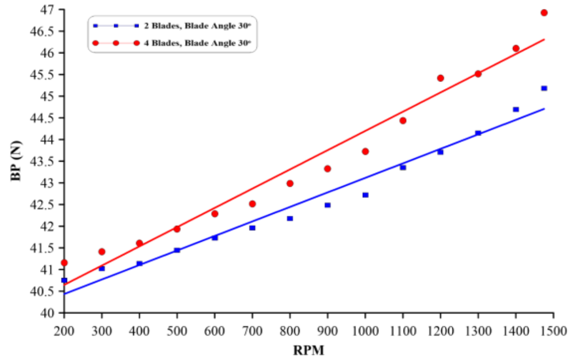

Figure 3.5 Effect of Number of Blades on Bollard Pull - Blade Angle 30^0

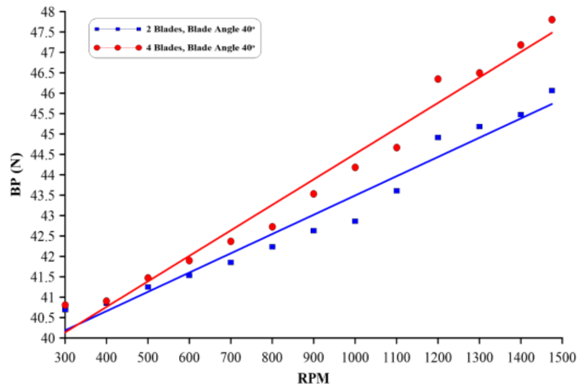

Figure 3.6 Effect of Number of Blades on Bollard Pull - Blade Angle 40^0

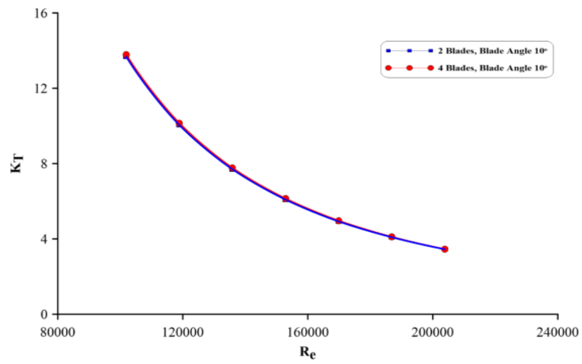

Figure 3.7 Effect of Number of Blade on Thrust Coefficient 10^0 Blade Angle

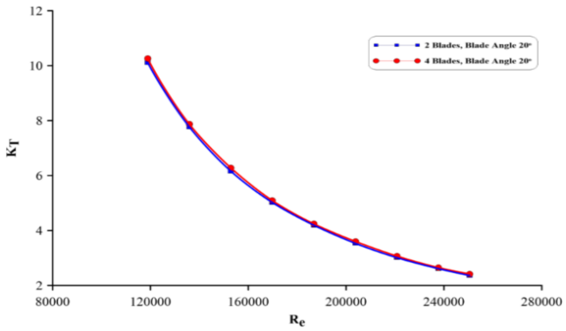

Figure 3.8 Effect of Number of Blade on Thrust Coefficient - 20^0 Blade Angle.

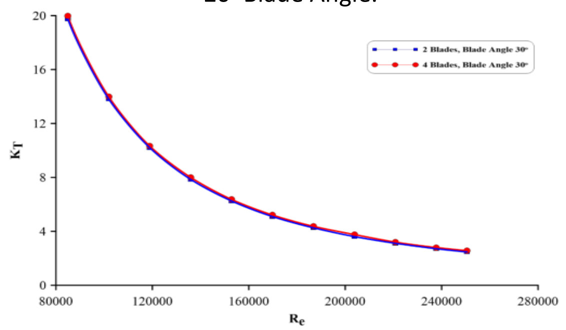

Figure 3.9 Effect of Number of Blade on Thrust Coefficient - 30^0 Blade Angle.

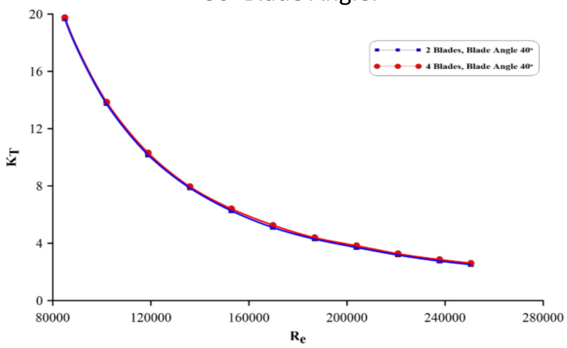

Figure 3.10 Effect of Number of Blade on Thrust Coefficient 40^0 Blade Angle.

3.4 Effect of Number of Blades on Thrust Coefficient of Ducted Propeller at Different Blade Angles

Effect of number of blades on the thrust coefficient at blade angle 10^0 the test results between 4 blades and 2 blades of propeller, it is found there is slightly increase between 1.19% and 1.58% at130000and 150000 Reynold's number respectively.

-Effect of number of blades on the thrust coefficient at blade angle 20^0 the test results between 4 blades and 2 blades of propeller (F) it is found there is an increase between 1.18%, 2.36,1.56and 1.63% at 130000,150000,180000 and 200000 Reynolds's numbers respectively.

-Effect of number of blades on the thrust coefficient at blade angle 30^0 the test results between 4 blades and 2 blades, it is found there is an increase between 1.87, 1.86, 2.19 and 3.74% at130000,150000,180000,and 200000 Reynold's numbers respectively.

-Effect of number of blades on the thrust coefficient at blade angle 40^0 the test results between 4 blades and 2 blades, it is found there is an increase between 0.46%, 2.00, 2.84 and 2.59% at130000,150000,180000 and 200000 Reynold's numbers respectively.

Table 3.6 Percentage of Bollard Pull for different Blade Angles

RPM	BP at blade angle 20^0	BP at blade angle 30^0	% increase than 20^0	BP at blade angle 40^0	% increase than 20^0
700	37.174	38.027	2.29	39.30278	5.72
800	37.272	38.694	3.81	39.9698	7.23
900	37.566	39.361	4.77	41.3825	10.15

3.5 Effect of duct tests

Using the designed duct, the tests are carried out for propeller model (E) and the exerted thrust are measured at different r.p.m

3.5.1 Effect of duct on the measured thrust

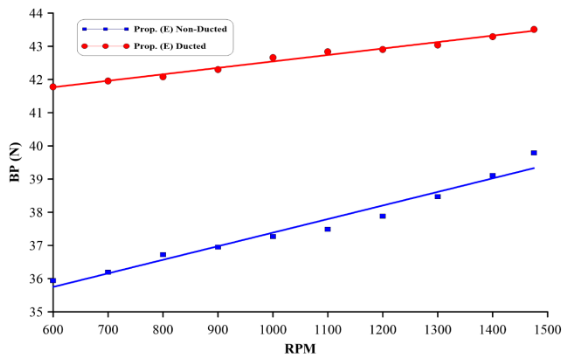

Figure 3.11 Effect of Duct on Bollard Pull for Propeller (E)

There is increase in the measured thrust of ducted propeller than non- ducted one between 9.35% to 16.24% as shown in fig (3.11)

3.5.2 Effect of duct on the thrust coefficient

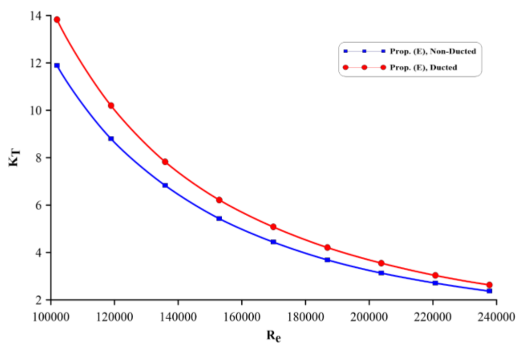

Figure 3.12 Effect of Duct on Thrust Coefficient for Propeller (E)

There increase in the thrust coefficient of ducted propeller than non-ducted between 13% to 15% at different Reynods׳s numbers as shown in fig (3.12)

Conclusion

The blade angle has an effect for improving the bollard pull thrust coefficient of the open propellers as it increases the propeller pitch diameter ratio.

The number of propeller blade has an effect in improving the bollard pull and the thrust coefficient, the increases of the propeller blades from two blades to four blades for the same propeller the bollard pull improves 0.2 to 3.7 % with the increasing of the propeller rpm.

The duct is improving the exerted thrust than the non - ducted propeller reach 15% as a maximum improving.

References

[1]. Port designers hand book: recommendations and guidelines.2003.thomas telford.111-115 p.
[2]. www.dieselduck.nemartinesmarine engineering page.17/8/201.
[3]. Dr.C.B.barrass,2011,shipdesigned performance for masters and mates, Elsevier butterworth,259p.
[4]. www.blog.mechguru.com 3/12/2013.
[5]. Carlton, John. Marine propellers and propulsion. Butterworth-Heinemann, 2012,89-91p.