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ANALYSIS OF THE MANOEUVRABILITY AND STRUCTURAL STRAIN OF A COORDINATED RUDDER ON AN OPERATIONAL TUG

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ABSTRACT

We have tested and compared the manoeuvrability of an operational tugboat with two different configurations of the steering system: the first one had a steering nozzle with a conventional fixed rudder blade; and the second had the same steering nozzle with a coordinated rudder, consisting of a pivoting flap fitted on the after part of the nozzle blade. It was found that the configuration using a coordinated rudder provided a considerable improvement in the low-speed manoeuvrability of the tug. We also developed equations for this coordinated rudder configuration which allow us to calculate the final turning diameter, the torque on the stock and the shear forces on the steering system of the tugboat as a function of the propeller shaft speed.

Key words: operational tug, steering system, coordinated rudder.

1. INTRODUCTION

The Kort nozzle was discovered in 1933 but its use for the propulsion of tugs, where traction is the main task, was not consolidated until the 1970s, after tests showed an increase in the bollard pull of 20% to 35%, depending on the design. Such a significant increase led to the gradual but widespread installation of fixed nozzles. There were two practical results: the pull was increased, which was advantageous; but manoeuvring capacity was limited, which was clearly negative. The limitation of the manoeuvring capacity produced by this system, together with the scarce effects of a conventional rudder with a fixed nozzle, led to the development of different systems seeking to improve the manoeuvrability.

A number of solutions have been tried to gain manoeuvring power. One of them was to install a transverse thruster at the bow. Various solutions have been fitted at the stern, such as active rudders, flap rudders, rotary cylinders, nozzle rudders, Shilling rudders, Tow Master, Becker and Rudder Coordinators. The most common way of solving the manoeuvrability problems encountered with a fixed nozzle on tugs was to replace it with a steering nozzle.

In recent years the manoeuvring problem has become even worse due to the reduced space left by crowded docks. In Spain, several harbour tugs have been fitted with either fixed or steering nozzles together with coordinated rudders. This solution provides greatly increased manoeuvring power at a low cost.

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This paper presents a short report of the manoeuvrability tests carried out with a real tugboat, 24 meters in length and with a power of 2050 bhp. The tests have been carried out with two types of steering arrangements: one had a steering nozzle with a conventional fixed rudder blade; the other had the same steering nozzle with a coordinated rudder. During the trials, turning circles were measured with a Global Positioning System (GPS) and the strains on the rudder and flap stock were determined by means of strain gauges.

2. EXPERIMENTAL METHODOLOGY

Within this conceptual framework we investigated two different types of parameters:
a) Those related to the shape and size of the turning circle.
b) The strain deformations on the rudder stock.

The results obtained have been arranged according to the two types of steering devices described above:

1. Steering nozzle with a fixed rudder blade.
2. Steering nozzle with a coordinated rudder.

The tugboat's manoeuvring capacity was tested by executing several series of six turning circles at sea. The first series of tests was carried out in Pasajes and the second in Santander. Both of these ports are located on the northern coast of Spain.

Each series of tests was performed in the order specified below:

1.- Engine speed 360 rpm, rudder hard-a-port.
2.- Engine speed 360 rpm, rudder hard-a-starboard.
3.- Engine speed 600 rpm, rudder hard-a-starboard.
4.- Engine speed 600 rpm, rudder hard-a-port.
5.- Engine speed 760 rpm, rudder hard-a-starboard.
6.- Engine speed 760 rpm, rudder hard-a-port.

3 EQUIPMENT

The equipment used in the trials was as follows:

- A real 24m tugboat.
- A steering system with rotating nozzle and fixed rudder.
- A steering system with rotating nozzle and a coordinated rudder.
- A topographic station.
- Experimental strain analysis gauges.

Main particulars of the tugboat

Length over al .... 26,80 m.
Length between perpendiculars .... 24,00 m.
Beam at design waterline .... 7,90 m.
Maximum draught .... 4,30 m.
Normal service draught .... 4,00 m.
Displacement at normal service draught .... 305 Tm.
Bollard poll .... 32,00 Tm.
Main engine .... 2050 bhp.
Speed .... 13,00 kt.

Steering system

Rudder torque .... 9000 m-Kg
Time for the rudder to go from one side to the other .... 12 s
Nozzle diameter .... 2136 mm^2
Area of the blade fixed to the nozzle .... 0,93 m^2
Attack angle of the turning nozzle 35

Coordinated rudder system (CT)

Area of the rudder blade .... 0,42 m^2
Area of the rudder flap .... 0,92 m^2
Attack angle of the nozzle and rudder blade 35º
Attack angle of the second rudder flap (with respect to rudder blade) 35º

With this steering system, when the nozzle rotates 35º, the flap rotates the same angle, actuated and synchronised by the rudder coordinator (CT), as shown in Figure 1.

Topographic equipment

Compact Station Geometer system .... Model 400
Global Positioning System .... GPS
Time between measurement .... 0.4 s
Maximum length .... 3100 m
Standard recording book
RS - 232C communication with a compatible PC

Strain measurement instrumentation

Technical data of extensometric bands:
Type FLA-6-11
Nominal resistance .... 120 Ohms
Gauge length .... 6 mm
Gauge thickness .... 0,0125 mm
Gauge factor 2,132

Trial results

The two tables below show the results of the trials. Table 1 refers to the conventional system of a steering nozzle with a fixed rudder blade. These trials were carried out in the approaches to Pasajes with a calm sea and no wind.

We show the average values of the turning circle diameter, together with the engine speed.

Table 2 shows the results of the second series of trials, after fitting a coordinated rudder, as shown in Figure 1. These trials were performed off Santander on 23 November 1992.

Table 1. Average diameters with steering nozzle and fixed blade

Engine speed	Side	Mean diameter
Slow ahead	Starboard-port	50 metres
Half ahead	Starboard-port	65 metres
Full ahead	Starboard-port	80 metres

The coordinated rudder consists of a rudder blade and a pivoting flap. The blade is fixed to the steering nozzle, and the flap is joined to the blade by means of a hinge. The main parts of the system are illustrated in Figures 1 and 2:

Figure 1: Schematic drawing of coordinated rudder

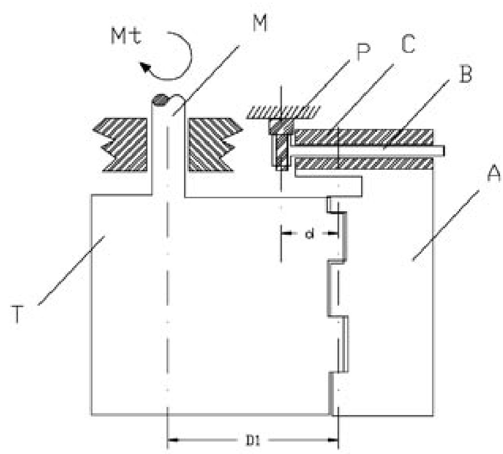
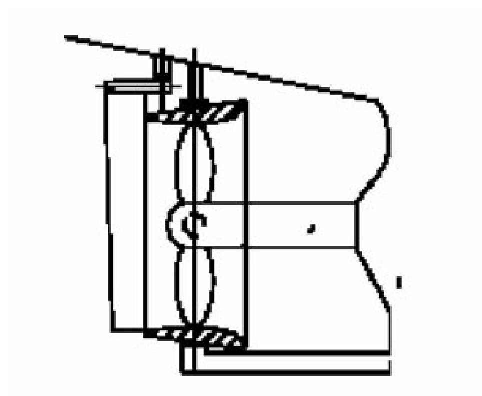


Figure 2: Detail of coordinated rudder



T = Nozzle A = Flap
M = Stock Dl = Distance between stock and flap axis
P = Pintle d = Distance regulating flap turning angle
C = Liner M_t = Rotating torque
B = Arm

During the second set of trials, meteorological conditions were excellent, as was the case during the first one in Pasajes. Therefore, we can assume that weather had no influence on the results.

Table 2. Average diameters with steering nozzle and CT rudder

Engine speed	Side	Mean diameter
Slow ahead	Starboard-port	20 metres
Half ahead	Starboard-port	25 metres
Full ahead	Starboard-port	35 metres

Figure 3 shows the shape and dimensions of the turning circle. Additional details about the manoeuvring data and conditions during the trials are presented in Table 3.

Figure 3: Turning circle with coordinated rudder

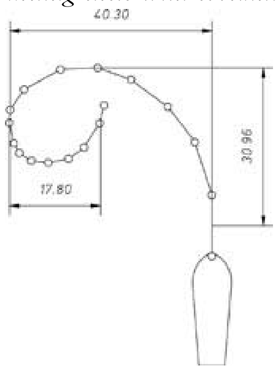


Table 3: Miscellaneous data on the turning manoeuvre

Engine RPM	360
Steering side	Port
Attack angle of the nozzle	35º
Attack angle of the flap	35º
Propeller RPM	120
Tug speed	2,28 kt
Length	24,00 m
Time to change heading 90º	18,10s
Time to change heading 180º	39,26s
Tug speed during steady turn	0,89 kt
Speed loss	70,13%
Advance	30,96 m
Tactical diameter D_t	40,30 m
Non-dimensional tactical diameter D_t /L	1,67
Steady turning diameter D_g	17,80 m
Non-dimensional steady turning diameter D_g/L	0,74

Table 4. Strain deformations on the coordinated rudder

Time in seconds	Torque on rudder stock m·Kg.	Torque on hydraulic system m·Kg.	Force on rudder flap m·Kg.
0	251	555	20
10	256	553	27
20	258	550	26
30	1858	1350	168
40	1249	1330	154
50	1688	1313	153
60	1418	1310	150
70	1519	1300	150
80	1554	1280	152
90	1553	1250	147

Table 5. Results of the trials

Time in seconds	Torque on rudder stock m·Kg.	Force on rudder flap m·Kg.
0	246	19
10	202	20
20	253	19
30	3637	329
40	2894	295
50	3343	300
60	3039	299
70	3107	298
80	3086	298

4. RESULTS

It can be seen that the manoeuvring capacity of the tug is about two and a half times better with the coordinated rudder system. We should point out that the relationship length / final diameter is less than one (when originally it was about 2). This means that the ship practically turns on the spot.

5. MATHEMATICAL EXPRESSIONS DERIVED FROM THE TEST DATA

Final turning diameter
The following expression is obtained
D = final diameter
P = Number of revolutions of the propeller shaft

$$D = 2.88 + 0.048 \cdot P \qquad \textbf{(1)}$$

The equation above gives acceptable results for propeller speeds from 100 to 300 rpm.

Relationship between propeller r.p.m. and torque on the stock

Many equations have been used to calculate the forces on the rudder stock, but for the configuration tested we propose the following:

M = Torque on the stock
P = Shaft revolutions

$$M(m \cdot KN) = -1037.9 + 20.5 \cdot P \quad \textbf{(2)}$$

Relationship between propeller r.p.m. and shearing forces on the CT rudder

Using the same parameters, the resulting formula is:

F = Shear force on the stock

$$F = -37.5 + 1.6 \cdot P \quad \textbf{(3)}$$

The above expressions are only valid for similar vessels with a CT system, in fine weather, with appropriate draught and a clean hull.

6. CONCLUSIONS

Tests performed on an operational 24m. tugboat showed that fitting a coordinated rudder on the steering nozzle provided a great improvement in low-speed manoeuvrability as compared to a steering nozzle with a conventional rudder. We also developed equations for this coordinated rudder configuration which allow us to calculate the final turning diameter, the torque on the stock and the shear forces on the steering system of the tugboat as a function of the propeller speed. As might be expected, we observed a moderate increase in the final diameter with an increase in the shaft speed. The torque and shear forces also increase with the speed of the propeller shaft.

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REFERENCES

Gutierrez, G, M.(1983). Extensometria y fotoelasticidad. Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos. Universidad de Cantabria. Santander.

Cueto, E. (1992). Coordinación de Timones en Remolcadores, Rotación, 288, p.35, 104, 1992.

Cueto, E. (1993). Coordinación de Timones en buques de pesca, Rotación, 292, p.96.

Cueto, E. (1992). Coordination of Rudders, n1 72, pag. 32, Oct.

Cueto, E. (1994). Las estaciones topográficas totales contribuyen al estudio experimental sobre la maniobrabilidad de los remolcadores, Topografía y Cartografía, ed C.O. de Ingenieros Técnicos en Topografía, Vol. 11 pp 9-15.

Cueto, E. (1994) Acción de la Tecnología del Coordinador de Timones en los Remolcadores, VI Congreso de la Marina Civil, Santa Cruz de Tenerife, España,

Cueto, E. Mendiola, S. (1994) Exigencias de la Tecnología del Remolcador Escort. VI Congreso de la Marina Civil, Santa Cruz de Tenerife, España, Por la Reactivación del Sector Marítimo.

Cueto, E. y González, A. (1985). Sistemas de Coordinación de Timones en Naves Náuticas. Patent application: 544.946

APÉNDICE: ANÁLISIS ESTRUCTURAL DE LA COORDINACIÓN DE TIMONES EN LOS REMOLCADORES

Nosotros hemos hecho una investigación en un remolcador que instaló un sistema "Coordinador de Timones" para accionar el Timón Articulado, de acuerdo con los siguiente proceso:

a) Las gráficas de las trayectorias descritas bajo las especificaciones de las maniobras evolutivas con el sistema de gobierno compuesto por: tobera móvil y timón, y las trayectorias descritas por el mismo remolcador durante una maniobra similar a la anterior con un sistema de gobierno compuesto por: tobera móvil, timón y alerón accionado por una coordinación de timones.

b) Las medidas estáticas/dinámicas evolucionando en el tiempo para obtener el par torsor que se produce en la mecha de la tobera móvil, durante las maniobras con la instalación de tobera móvil, timón y alerón accionado por un coordinador de timones

SISTEMA DE COORDINACION DE TIMONES PARA NAVES NAUTICAS

Según la figura 1, está compuesto por dos palas de timón situadas en línea, unidas por una articulación vertical, denominados respectivamente timón y alerón, el timón está accionado por la mecha, que le llega el accionamiento del servo y el alerón es movido por medio de un sistema mecánico por los ejes, los cuales forman un subsistema de accionamiento compuesto por un pistón deslizante, en una camisa, este pistón pivota en un pinzote fijo.

El coordinador de timones funciona según la figura, cuando se mete timón a cualquier banda. En la situación de navegar con el timón a la vía no produce efecto. Vamos a estudiar el caso de poner el mando o rueda de cabillas para situar todo el timón a la banda, produciendo un giro en el timón de á 35 º y en el alerón â 70º.

Estos dos timones calados con los ángulos gobernados automáticamente por el sistema de ejes, produce un avance de grados en el giro del alerón superior al del timón, según podemos apreciar en las figuras.

METODOLOGIA EXPERIMENTAL

En los ensayos se han obtenido dos tipos diferentes de datos, que están diferenciados claramente:

1.- Los referentes a las maniobras
2.- Los que reflejan las deformaciones.

METODOLOGIA DE: FUERZAS Y PAR TORSOR

Se utilizo para la obtención de las fuerzas y pares torsores la extensometria.
LA EXTENSOMETRIA: es el método que tiene por objeto la medida de las deformaciones superficiales de los cuerpos.
Las medidas se realizaron estáticas/dinámicas, tomando la evolución de los esfuerzos en el tiempo.
Se calcularon los esfuerzos a partir de las medidas extensometricas
El extensómetro eléctrico de resistencia es un hilo conductor de pequeño diámetro que al deformarse modifica su resistencia. En consecuencia, transforma una deformación en algo medible eléctricamente.
Expresando la variación de resistencias debida a la deformación, con signo indicativo que es negativa para la banda de estribor por trabajar a compresión y positiva para la banda babor por trabajar a tracción; el segundo sumando de expresa la variación de resistencia con la temperatura.

TRANSDUCTORES DE PRESION CON GALGAS EXTENSOMETRICAS

Estos transductores utilizan como sensores primarios o elementos elásticos los diafragmas Se pegan a ellos cuatro bandas extensométricas.

RECOGIDA DE DATOS EXTENSOMETRICOS

Las mediciones extensométricas fueron recogidas cada diez segundos en la base de datos del ordenador durante la realización de las maniobras descritas en el apartado A del presente capítulo.

MATERIALES
Los materiales empleados en este trabajo son los siguientes:

- Un remolcador escala 1:1, buque real.
- Un sistema de coordinación de timones instalado.
- Un equipo de topografía.
- Un equipo de instrumentación de extensometría.

CONCLUSIONES

La investigación se refiere a ensayos en un buque a escala 1:1.

1.-Se aprecia como un aumento en el numero de revoluciones de la hélice origina unos esfuerzos mayores (en este caso mayor momento torsor en la mecha y momento flector en el brazo) en los elementos del sistema de gobierno con la coordinación de timones.

2.- Tras analizar los resultados obtenidos en las diferentes maniobras para el momento torsor en la mecha, hemos llegado a la conclusión de que dichos puntos podrían ajustarse a una senoide amortiguada.

3.- El índice indicativo de el diámetro de giro final entre la eslora para el caso de media máquina se aproxima a 3, mientras que con coordinación de timones es prácticamente la unidad.

4.- El incremento en el número de revoluciones de la hélice supone un aumento del diámetro de giro final. No obstante el índice de el diámetro por la eslora rebasa ligeramente el valor de 1,5 siendo 3,3 en origen., la capacidad de maniobra del buque sea mayor a pocas revoluciones de la hélice.