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ANALYSIS OF A 300HP TUG STEERING GEAR SYSTEM WITH A VIEW TO UPGRADING IT

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ABSTRACT

The article deals with the calculation of the hydraulic installation in the steering gear of a 300HP tug, aimed at replacing the formerly used manually operated steering system. Technical design data are provided for the hydraulic steering gear.

Keywords: steering system, hydraulic system, tug 300 HP.

1. INTRODUCTION

Ship steering ensures ship manoeuvrability. Ship manoeuvrability is the property of the ship to maintain course on a given direction and to move under the action of external, propulsion and steering forces on a given trajectory. These two aspects of ship steering determine two different regimes in the operation of the installation [1]:

- march regime, characterised by rare changes of direction;
- maneuver regime - changes of direction.

Ship manoeuvrability consists in the performance parameters defined upon ship building:

- gyration parameter which approximates the circle described by the ship when the rudder is banded. The smaller it is, the better the maneuverability.
- the zigzag test.
- the spiral test. The rudder is banded on one side and the ship starts gyrating.

2. CLASSIFICATION OF THE STEERING GEAR

From the point of view of the forces transmitted to the ship in order to be steered, steering gear may be [1]: active or passive.

In the active steering gear, steering forces are obtained through special propellers involving energy consumption on board.

In the passive steering gear, steering forces are obtained from the interaction between the working instrument (rudder) and the water current, the energy being consumed only to position the instrument within the current.

According to the action mode of the active organ, the steering gear may be operated manually, electromechanically, electrohydraulically or by means of steam.

According to its type, the steering gear may have mechanical, electrical, hydraulic or electrohydraulic transmission.

3. COMPONENTS OF THE STEERING GEAR

The transmission of the steering gear may be force or command transmission.

Force transmissions achieve the power transfer from the machine to the rudder axis. These transmissions may be [1]:

- helm;
- sector.

The transmissions will get the motion from the rudder via a reductor or a hydraulic system. The helm or the sector may be distance-commanded, usually in manual operation through shafts, chains or bars. Command transmissions link the command post of the steering gear (the steering wheel) to the steering machine, commanding the movement of the rudder and the continuous transmission of the rudder position to the axiometer. These transmissions may be: mechanical (by means of shafts, bars, chains), electrical or hydraulic.

4. ANALYSIS OF THE STEERING GEAR OF A 300 HP TUG

The ship under analysis is a 300 HP tug with the following main features:

- L_{max}=26.3m - T=1.72m
- D=5.1m - v_{max}=16km/h.

The present steering gear of the ship is fitted with a compensated rudder. The rudder is unprofiled, a steel plate 15mm thick, welded to the rudder post. On top of the rudder post there is a helm with D=1800 mm to an angle of 100^0. The rudder post is supported by three sliding bearings.

The operation of the rudder is performed manually, by means of cables, guided by a carrier set. Due to high friction and the long cable trajectory, the manual operating effort of the rudder is extreme. That is why it is desirable to replace manual operation by hydraulic operation. In this regard the paper performs the calculations for the hydraulically-operated steering wheel.

The paper deals with a steering gear of the DPS 1600T type with the following characteristics:

- maximum torque 1600 [daNm]
- average angular speed of rudder positioning min 4/s
- maximum working pressure 85 kgf/cm^2
- banding angle ±35°
- diameter at helm 104 mm
-operation:two-pump hydraulic group 3.7Kw
- input voltage 370V, 50Hz.

4.1 Determination of force and momentum acting on the rudder

a) *Determining the rudder force*

The selected rudder is rectangular, unprofiled (single plate) having the size 1650x1410 mm, supported by a cutwater in the lower section.

a) the force acting on the rudder is [2]:

$$C_R = 28.86 \cdot (1+n)^{0.15} \cdot A \cdot V_{av}{}^2 \cdot r_1 \cdot r_2 \cdot r_3 \quad (1)$$

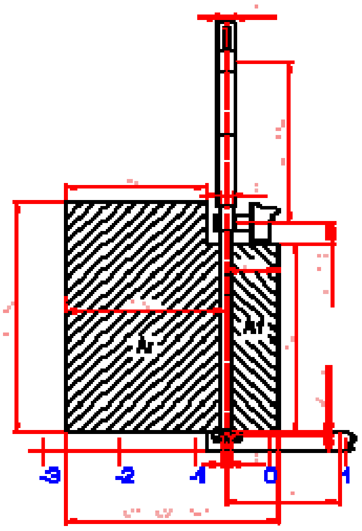

Fig. 1 The rudder

- $v_{AV} = 16[km/h]$ the maximum speed of the ship on way forward
- $v_{AD} = 13.5[km/h]$ the maximum speed of the ship on way backwards
- $r_l = (\lambda + 2)/3$ shape factor
- $h = 1.65[m]$ maximum rudder height
- $hm = 1.50[m]$ average rudder height

$$A_r = 1.65 \cdot 1.06 = 1.749[m^2]$$

- A_r area in the bow of the rudder axis

$$\begin{aligned} A = A_T = A_r + A_f \ [m^2] \\ A_f = 1.35 \cdot 0.35 = 0.472[m^2] \end{aligned} \quad (2)$$

- $r_2 = 1$ for a single plate
- $r_3 = 1$ coefficient according to the rudder position as compared to the propeller jet
- $n = 0.85\,H$ coefficient accounting for the wave height
- $H = 0.6[m]$ wave height

$$\Rightarrow C_R = 20683.42\ [N]$$

b) *Determining the rudder torque*

The rudder torque for way forward and backward may be found by means of the following expression [2]:

$$M_{TR} = C_R \cdot r\ [Nm] \qquad (3)$$

where:

- $r = b \cdot (\alpha - A_F / A)$ arm of the force
- $b = 1.41\ [m]$ rudder width
- $\alpha = 0.33$ for way forward
- $\alpha = 0.66$ for way backward

$$\Rightarrow \begin{cases} r = 0.165\ [m]\ \text{for way forward} \\ r = 0.631\ [m]\ \text{for way backward} \end{cases}$$

$$\Rightarrow \begin{cases} M_{TR} = 3412.764\ [Nm]\ \text{for way forward} \\ M_{TR} = 13051.238\ [Nm]\ \text{for way backward} \end{cases}$$

The steering wheel will have a maximum moment of 1.6 Tm.

$$\Rightarrow M_{TR\max} = 16000\ [N]$$

the maximum moment of the steering wheel.

4.2 Sizing the rudder post

The higher diameter of rudder shaft [2]:

$$d_T = 4.2 \cdot (M_{TR} \cdot K_1)^{1/3}\ [mm] \qquad (4)$$

- $K_1 = (235 / R_{eH})^{1/3}$ material coefficient

The material of the rudder post is OLC35X (R_{eH}=300 N/mm^2 flowing limit, R_{eH}=530 N/mm^2 breaking limit).

- n_l=0.75

The post diameter in the upper part is: d_T = 99.54 [mm] the existing diameter Ø105 [mm]. The cutwater diameter may be 0.75d_T. dp = 74.655 [mm], the diameter of the cutwater existing on the ship is Ø80 [mm]

4.3 Sizing the rudder plate

The rudder is unprofiled. The rudder has a low-positioned cutwater. The rudder post aboard the ship has a diameter of Ø105 mm in the upper part, and a diameter of Ø85 mm near the middle bearing.

a) Calculation of the rudder plate thickness:

$$t_B = (0.81 \cdot s \cdot V_{AV} + 2.5)\sqrt{K} \qquad (5)$$

- s = 0.850[m] the space between ribs
- K = 0.821 material factor

$$\Rightarrow t_B = 12.245[mm]$$

The thickness of the rudder plate on the ship is t_B = 15 [mm].

b) Determining the necessary rib resistance module [2]

$$Z_A = 0.15 \cdot s \cdot C_H^2 \cdot V_{AV}^2 \cdot K[cm^3] \qquad (6)$$

- C_H = 1,060 m horizontal distance from the bow edge of the rudder to the rotation axis

$$\Rightarrow Z_A = 30.109[cm^3]$$

c) Determining the rib height [2]

$$W = b \cdot h^2 / 6 = 30.109[cm^3] \qquad (7)$$

- b = 1 cm rib thickness → h = 13.44 cm

The existing rib is :

- b = 10 mm rib thickness and
- h = 95 mm rib height

The ribs will be replaced

d) Heel thickness check (cutwater)

$$t = 1.3\sqrt{L + 0.1P_l} \qquad (8)$$

where P_l = 221 kw propulsion engine power.

$$\Rightarrow t = 9.044[mm]$$

The thickness by the ship is 90,0 mm.

e) The bending moment [2]

$$M_s = F_{Ai} \cdot X \qquad (9)$$

- $F_{Ai} = C_R / 2$ axial force admitted
- X=0.75 - heel arm

$$\Rightarrow M_s = 7756.282[Nm]$$

f) Minimum module for the heel section [2]

It is required that the module should not be lower than the value obtained by the formula:

$$\begin{gathered} W_y = 0.5 \cdot W_z = 147\ [cm^3] \\ W_y = a \cdot b^2 / 6 \end{gathered} \qquad (10)$$

- b = 9 [cm] and a = 14 [cm]

$$W_y = 189[cm^3] \geq 147[cm^3]$$

4.4 Thickness "s" of the blade of a flat (unprofiled) rudder [3]:

$$s = 1.25\sqrt{L} = 6.41[mm] \qquad (11)$$

In tugs, the thickness of the metal covering the rudder blade should be increased by 10%.

Therefore s = 6.41x 1.1 = 7.05 mm.
The thickness of the rudder plate on the ship is s = 15 mm.

4.5 Resistance module W for horizontal ribs [3]:

$$W = 94.14 \cdot t \cdot l_1^2 \cdot v^2 / R_{eH} \, [cm^3] \qquad (12)$$

- t=0.85 [m], the maximum distance between the rudder ribs,
- l_1=1.06 [m], the distance between the bow-side edge of the rudder and the rotating post.

$$\Rightarrow W = 97.943 [cm^3]$$

In tugs, the resistance module of the horizontal ribs will be increased by 20%, so:

$$\Rightarrow W = 117.531 [cm^3]$$

$$W = b \cdot h^2 / 6 = 117.531 \rightarrow h = 26.55 [cm]$$

Hence, the horizontal rib should be increased in heigth, to 300mm, which is feasible.

4.6 The rudder post [3]

a) The diameter of the Head of the rudder post "d_0" should not be lower than :

$$d_0 = 8.65 \cdot \sqrt[3]{A \cdot r_1 \cdot v^2 / R_{eH}} \qquad (13)$$

- r_1=0.222 m the distance between the weight center of the rudder surface and the rotating post, [m]. This value should not be lower than 1/3 of the distance between the rotating rudder post and the bow-side edge of the rudder blade, i.e.:

$$\rightarrow d_0 = 9.333 \, [cm]$$

b) The diameter d_1 of the rudder post in the bearing above and below the rudder blade should not be lower than:

$$d_1 = 0.58 \cdot d_0 \cdot \sqrt[3]{C_1 / r_1} \, [cm]$$

$$C_1 = \sqrt{C_2^2 \cdot h^2 + 48 \cdot r_1^2} \, [m] \qquad (14)$$

$$C_2 = 2 - (h/h_1)^2$$

- h = 1.380[m] the distance between the middle of the lower bearing of the rudder blade and the upper edge of the rudder blade,
- h_1=1.538 m, the distance between the middle of the lower bearing of the rudder post and the middle of the first bearing above the rudder blade .

$$\Rightarrow d_1 = 11.287 [cm]$$

The diameter of the post existing on the ship is d1= Ø85 mm, which has to be increased to Ø115 mm.

The helm is above the upper bearing, in which case the diameter of the post by the bearing should not be lower than :

$$d_3 = d_0 \cdot \sqrt[3]{C_4} = 10.311 [cm] \qquad (15)$$

The diameter of the post existing on the ship is d_3= 110 [mm].

When the rudder post extends to the lower edge of the rudder blade, the diameter of the lower end of the rudder post may decrease by 60% of the diameter d_1.
The lower diameter=0.6·11.287 = 6.772 cm.
The lower diameter existing on the ships is = Ø80 mm

5. CONCLUSIONS

1. The ribs of the rudder blade will be replaced by the ribs resulting from calculations, i.e.: b = 15 [mm] rib thickness and h = 135 [mm] rib height.
2. To prevent the upwards displacement of the post and rudder, a stopper will be welded to the rudder blade.
3. According to regulations, the heigth of the horizontal ribs on the rudder blade should be increased from 95 mm to 300mm, which is entirely feasible.
4. The diameter of the existing post is d_1= Ø85 mm, which should be upgraded to Ø115 mm.
5. As a result of this upgrade in the steering gear, the ship maneuverability and sailing safety will consequently increase.

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