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Improving Education for Future Marine Electromechanics Through Experimental Analysis of Hydrostatic Pressure in Liquids Using the HM 150.05 Experimental Unit

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***Abstract*—This study examines the integration of practical experimental methods into the Thermodynamics and Fluid Mechanics course for students specializing in Ship Electrical Equipment, focusing on understanding hydrostatic pressure in liquids. Using the HM 150.05 experimental unit, available in the Applied Mechanics Laboratory, the research aims to bridge theoretical knowledge with practical application. The experiment not only reinforces key principles linking thermodynamics and fluid mechanics but also provides students with a tangible understanding of the forces acting in the marine environment. The results highlight the effectiveness of experimental analysis in enhancing student comprehension and engagement.**

Keywords — education, experimental learning, HM 150.05 experimental unit, hydrostatic pressure, Thermodynamics and Fluid mechanics.

I. INTRODUCTION

Education in the specialization of marine electrical equipment requires a solid foundation in courses in thermodynamics and fluid mechanics, especially to understand the behaviour of fluids when changing key thermodynamic parameters such as pressure.

HM 150.05 unit [1] serves as the main tool for providing students with practical experience in analysing hydrostatic pressure. This study offers a method for integrating this experimental unit into the educational process to enhance its efficiency.

Trainees specializing in Ship Electrical Equipment should be familiar with the basic principles of fluid mechanics. Sources [2] and [3] can be used in the educational process. These books provide an accessible explanation of the causes of hydrostatic forces acting on various walls and curved surfaces, as well as how hydrostatic pressure is distributed in liquids. They also emphasize the significant influence of the fluid's depth on pressure and how this, in turn, affects submerged walls.

Once the trainees are familiar with and understand the core aspects of hydro-mechanics and have conducted the experiment, they can gain a practical understanding of the processes related to hydrostatic pressure in various ship structures and constructions. In [4] and [5], a detailed overview of the shipbuilding process is provided, including design, materials, structures, and systems. These sources examine the different stages of ship construction, from initial designs to the final built structure. In this context, understanding hydrostatic pressure and how it affects ship hulls, as well as ways to ensure the safety and stability of ship structures, the overall stability of the entire ship, and the effects of various loads, is of paramount importance for the entire crew and especially for mechanics and electricians.

The source [6] provides specialized information on hydraulic and pneumatic systems, covering key principles, components, and their application in engineering practice. The book can be used by both technicians and engineers, offering both theoretical explanations and practical examples related to thermodynamic principles of pressure, forces, energy conversion, and the importance of these systems in various industrial applications.

For future marine specialists studying Thermodynamics and Fluid Mechanics, it is crucial to understand how hydrostatic pressure influences the components of electromechanical systems. In [7], the

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dynamic characteristics and stability of electro-hydrostatic actuation systems, which use hydrostatic pressure for controlling mechanical movements, are explored.

Good theoretical preparation, conducting experiments using professional unit HM 150.05 type and connecting them with practical examples, will significantly increase and improve the knowledge and preparation of the trainees for their future practice at sea.

II. MATERIALS AND METHODS

HM 150.05 unit is designed to measure hydrostatic pressure in liquids at various depths. This demonstration allows students to establish the change in pressure with depth using the basic principle

$$p = \rho g t, \qquad (1)$$

where: p, Pa – hydrostatic pressure.

ρ, kg/m^3 – density of water.

g, m/s^2 – gravitational acceleration ($g=9,81\ m/s^2$);

t, mm – depth of the water column above the measurement point.

Fig. 1. HM 150.05 experimental unit.

Fig. 1 shows the HM 150.05 experimental unit, consisting of the following elements [1]:

1 – Water tank; 2 – Water level scale; 3 – Locking pin; 4 – Sliding weight; 5 – Stop pin;6 – Slider;7 – Weights.

The study is conducted through a series of experiments, including measuring the hydrostatic pressure at different angles of inclination of the water tank and recording the water levels. The experiments are carried out in the sequence described in the induction [1].

By calculating the hydrostatic pressure, the substitute force F_p is determined, which considers the pressure of the water on the curved wall. The experiment can be carried out at an angle of the water tank of $\alpha=0°$, $30°$, $60°$ and $90°$. In the present work, the results are shown only for the tank inclination of $0°$ and $60°$.

The methodology of conducting the experiment is carried out in the following sequence:

- Determine the centre of pressure P, which is the point of application of the substitute force F_p, Fig. 2;

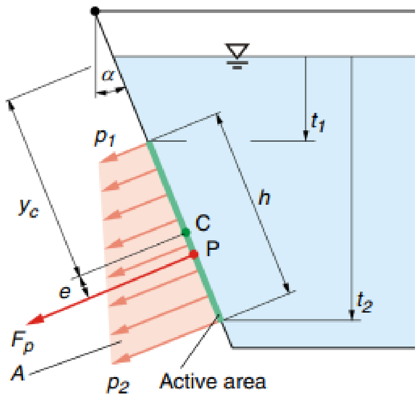

Fig. 2. Substitute force [1].

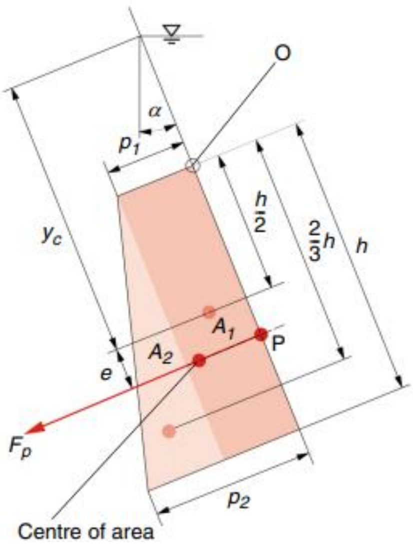

Fig. 3. Centre of pressure [1].

Fig. 3 shows the linear profile of pressure as depth t changes and how the distance e between the center of pressure P and the center of gravity C of the active area is determined.

- Determine the substitute force F_p at $0°$ and $60°$ position of the water tank, respectively [1].

The hydrostatic pressure acting on the active area A can be defined as a substitute force F_p whose directrix passes through the center of pressure P. The magnitude of this substitute force corresponds to the hydrostatic pressure at the center of gravity C of the active area:

$$p_c = \rho g t_c, \qquad (2)$$

where: p_c, Pa – hydrostatic pressure in the center of area of the active area.

ρ, kg/m^3 – density of water.

g, m/s² – gravitational acceleration ($g=9{,}81\ m/s^2$);

t_c, *mm* – vertical distance of the center of area from the liquid surface.

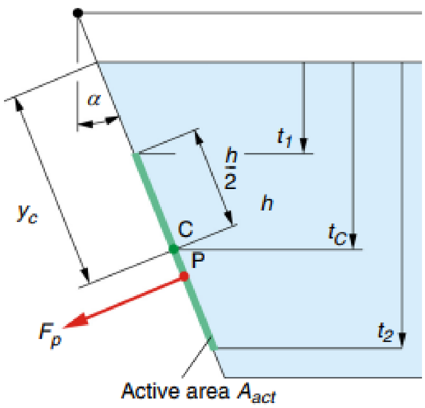

Fig. 1. Substitute force [1].

The substitute force can be found [4]:

$$F_c = p_c A_{act}, \quad (3)$$

The following assumptions are made for conducting the experiment:

- $\rho=1000\ k/m^3$ – water density;
- $g=9.81\ m/s^2$ – gravitational acceleration;
- $b=75\ mm$ – width of water tank.

- Determining I_p – the distance from the centre of pressure P to the support point of the experimental unit.

After determining the hydrostatic pressure and the substitute force, the following is the determination of *e* – the distance between the centre of pressure P and the centre of the active area. It is involved in the formula for determining I_p. These two characteristics are calculated using different formulas depending on the slope of the water tank and the height of the water column.

$$I_p = 150mm + e \quad (4)$$

- Determination of the resultant moment M_p, the moment from the calculated values M_W and the error in percentage, i.e. the dispersion in percent [4]:

$$M_p = F_p I_p, \quad (5)$$

$$M_W = F_W I_W, \quad (6)$$

where: F_w, *N* – weight force;

I_W, *mm* – lever arm.

$$\frac{M_p - M_W}{M_p} 100\%. \quad (7)$$

A. Calculation of hydrostatic pressure for a non-inclined water tank – 0° position of the water tank

Fig. 5 shows how the distance I_p is calculated from the center of pressure P to the fulcrum of the experimental unit (lever arm). At a water level *s* above the *100 mm* mark, the active area always has a height of *100 mm*. This means that the hydrostatic pressure on the active area has a trapezoidal profile. The hydrostatic pressure at the center of gravity is calculated using formula (8) [1].

$$p_c = \rho g(s - 50\ mm), \quad (8)$$

where: *s, mm* – measured water level *h*.

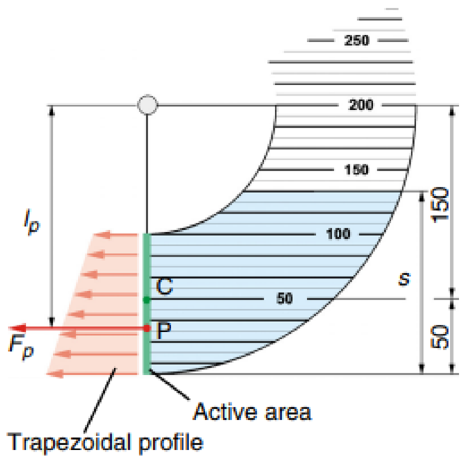

Fig. 4. Water level s>100 mm [1].

The area of the active area is calculated using the formula (9) [1]

$$A_{act} = b100\ mm. \quad (9)$$

The resulting substitute force is determined by the formula (10) [1].

$$F_p = p_c A_{act}. \quad (10)$$

The distance *e* between the centre of pressure P and the center of area C of the active area is determined by formula 11 [1], and the distance I_p by formula 12 [1].

$$e = \frac{1}{12}\frac{(100\ mm)^2}{s - 50\ mm}, \quad (11)$$

$$I_p = 150\ mm + e. \quad (12)$$

The results of the water level measurements and calculations for the moment show that with increasing gravity force F_W and displacement force F_p, the water level *h* increases, which is expected. At different angles of positioning of the water tank (*0°* and *60°*) we observe different values of the measured characteristics.

The results obtained from the measurements and calculations of the main characteristics at a water tank position of *0°* are shown in Table 1 and Table 2.

TABLE 1 RESULT OF MEASURED WATER LEVEL

Measurement №	Lever arm l_w, mm	Weight force F_w, N	Water level h, mm
1	140	0	-
2	140	1	50
3	140	1.5	60
4	140	2	69
5	140	2.5	78
6	140	3	84
7	140	4	98
8	140	5	110
9	140	6	122
10	140	7	136

TABLE 2 RESULT OF CALCULATED CHARACTERISTICS BASED ON MEASURED WATER LEVEL

Measurement №	Substitute force F_p, N	Lever arm l_p, mm	Moment M_p, Nmm	Moment M_W, Nmm	Variance %
1	-	-	-	-	-
2	0.92	183.3	168.6	140	20.4
3	1.32	180	238.3	210	13.47
4	1.75	177	310.3	280	10.8
5	2.24	174	389.4	350	11.25
6	2.59	172	445.5	420	6
7	3.53	167.3	590.7	560	5.4
8	4.41	163.9	722.8	700	3.25
9	5.3	161.6	856.5	840	1.96
10	6.33	159.7	1010.9	980	3.1

At the *0°* position, the percentage error decreases with increasing force, starting at *20.4%* and decreasing to *1.96%* at the end.

Permissible error: *5% – 15%* for experimental measurements in engineering disciplines.

At the *0°* position, the errors are within the permissible limits, indicating that the experiment was successful.

B. Calculation of hydrostatic pressure for an inclined water tank – 60° position of the water tank

The difference between the analysis of an inclined and a vertical water tank lies in the conversion of the water levels to inclined active areas: The factor *cosα* must be considered. Even when the water tank is inclined, a triangular profile is obtained for the pressure curve when the water level is below s_u and a trapezoidal profile, as shown in Fig. 6 and Fig. 7.

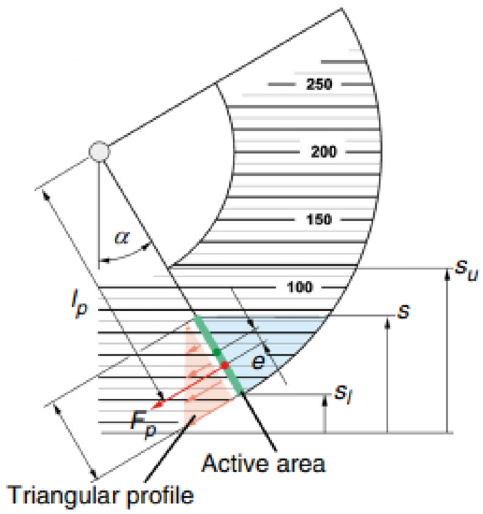

Fig. 5. Water level $s<s_u$ [1].

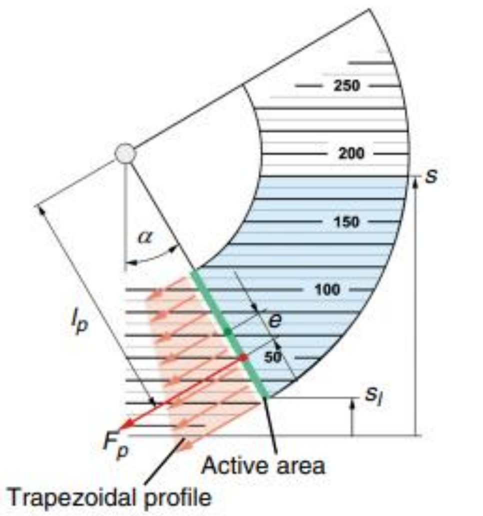

Fig. 6. Water level $s>s_u$ [1].

Before reading the water level *h*, it is necessary to read the water level at the lowest point of the water tank s_l and the water level at the upper edge of the active area s_u. This is done because when calculating the main characteristics mentioned above, there is a comparison with the read water level s, which is h, with the parameter s_u.

At water level $s<s_u$ the pressure profile is triangular Fig. 6, then Formulas 13, 14 and 15 are used to calculate the parameters h, e and I_p [1].

$$h = \frac{s - s_l}{\cos\alpha}, \quad (13)$$

$$e = \frac{1}{6}h, \quad (14)$$

$$I_p = 200mm - \frac{1}{3}h. \quad (15)$$

At water level $s>s_u$ the profile is trapezoidal Fig. 7, then Formulas 16 and 17 are used to calculate the. parameters e and I_p [1].

$$e = \frac{1}{12} \cdot \frac{(100)^2}{\frac{s - s_l}{\cos\alpha} - 50mm}, \quad (16)$$

$$I_p = 150mm + e. \quad (17)$$

The next step is to determine the hydrostatic pressure at the centre of the area p_c, the area of the active area A_{act}, and the substitute force for hydrostatic pressure on the active area F_p. Here again, a comparison is made between the water level (which is the reported water level) and the water level at the top edge of the active area.

Again, different formulas are used to determine the above-mentioned characteristics depending on the pressure profile.

For a triangular profile (Fig. 8), Formulas 18 and 19 are used for $s<s_u$

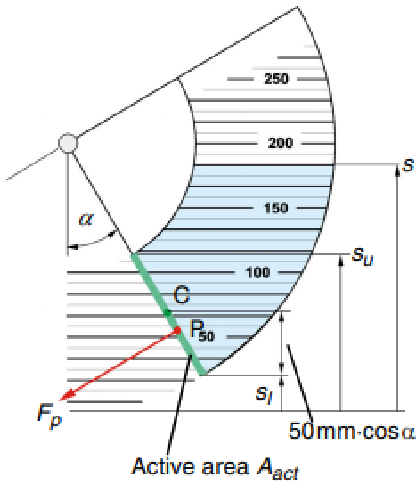

Fig. 7. Vertical water tank [1]

$$p_C = \rho g \frac{s - s_l}{2}, \quad (18)$$

$$A_{act} = \frac{s - s_l}{\cos\alpha} b. \quad (19)$$

and for a trapezoidal profile for $s>s_u$, Formulas 20 and 21.

$$p_C = \rho g (s - s_l - 50mm \cos\alpha), \quad (20)$$

$$A_{act} = 100mm.b. \quad (21)$$

The resulting substitute force is calculated by the Formula 5.

To calculate the resultant moment from the calculated force, the resultant moment from the measured force and the dispersion in %, the formulas already cited above as in [1] used in the calculation of these characteristics at *0°* position of the water tank are used.

The results obtained from the measurements and calculations of the main characteristics at a water tank position of *60°* are shown in Table 3 and Table 4.

TABLE 3 RESULT OF MEASURED WATER LEVEL

Measurement №	Lever arm I_w, mm	Weight force F_w, N	Water level h, mm
1	140	1	130
2	140	1.5	140
3	140	2	147
4	140	3	158
5	140	4	170
6	140	5	182
7	140	6	194
8	140	7	206
9	140	8	220

TABLE 4 RESULT OF CALCULATED CHARACTERISTICS BASED ON MEASURED WATER LEVEL

Measurement №	Substitute force F_p, N	Lever arm I_p, mm	Moment M_p, Nmm	Moment M_W, Nmm	Variance %
1	0,497	182,67	90,79	140	35
2	0,954	176	167,9	210	20
3	1,360	171,33	233	280	17
4	2,134	164,37	350,8	420	16
5	3	160,20	480,6	560	14
6	3,9	157,86	615,6	700	12
7	4,78	156,41	747,6	840	11
8	5,81	155,41	902,9	980	8
9	6,7	154,58	1035,7	1120	75

At *60°*, the variation of the moments *(% error*) remains relatively low until measurement *8* (*8%*), but at measurement 9 it suddenly increases to *75%*, indicating a significant difference between the experimental and theoretical results.

In engineering experiments, the permissible error depends on the accuracy of the instruments and the application. The usual limits are:

Tolerable error: *5%-15%* for experimental measurements in engineering disciplines.

If the error exceeds *20%*, this may indicate:

- problems with the measuring instruments;
- human factor (error in reading);
- inaccuracies in the theoretical model.

At *60°*, the error up to *8%* is within normal limits, but the value of *75%* in the last measurement indicates a serious deviation. Possible reasons:

- incorrect reading of the water level;
- a problem in the experimental setup;
- an error in the calculations.

III. Results and Discussion

The experiments show that the HM 150.05 experimental unit provides accurate and reproducible data, allowing students to verify the basic hydrostatic laws. The data are analysed to demonstrate the dependence of pressure on depth and the inclination of the tank. Possible sources of errors are discussed, and how they can be minimized.

IV. Other Recomendations

A. Review measurements for values with high error.

Check methodology and instruments.

B. Comparison with theoretical model.

If the difference remains large, the bench may need to be calibrated.

C. Repeat measurements.

For values with high error (e.g. *75%*) it is good to repeat the experiment.

V. Conclusions

The use of the HM 150.05 unit in Thermodynamics and Fluid Mechanics course significantly enhances the educational process for students in shipbuilding and electrical engineering. Through direct participation in experiments, students gain a deeper understanding of basic principles and develop practical skills necessary for their future careers. This also stimulates their interest in scientific research and innovation in the field of marine engineering.

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