UDK: 623.438.3-57(047)=20
COSATI: 19-03, 21-10, 12-01

Some parameters of engine operation obtained by mathematical modelling of underwater tank driving

Milić Ivošević, MSc (Eng)[1)]

This work presents the assumptions and values determined experimentally under laboratory conditions used to form a mathematical model for simulation of underwater driving and water obstacle overcoming. The theoretical conditions of tank movement are also given. The mathematical model for simulation of underwater tank driving was used to acquire certain parameters referring to engine operation and they are shown as diagrams.

Key words: **tank, underwater driving, engine, pressure, fuel, heat quantity, mathematical model.**

Introduction

HIGH sustaining rate of contemporary combat operations requires tanks to cross rivers or other water obstacles very quickly, with or without the use of special devices, depending on the characteristics of obstacles.

This possibility contributes considerably to the increase of mobility and soft-ground performances of tanks.

Tanks cross water obstacles in two ways:

- by wading, and
- by driving underwater.

Without any particular preparation, tanks overcome by wading the water obstacles that most often range from 1.2 to 1.5 m, which depends on the construction of the armoured body, or on the position (elevation) of the turret seat, air inlets and outlets, engine cooling system, etc.

Tanks use underwater driving to overcome water obstacles up to 5 m in depth, which requires special preparations and building-in of additional equipment.

Although quite specific, overcoming water obstacles by wading (with certain approximation) can be considered as tank movement under heavy-duty service conditions.

The underwater driving is carried out under special conditions of movement and service which require heavy-duty operations of some sub-systems. Under such conditions it is the engine that is most endangered and thus requires a special study.

The problems of underwater tank driving were subjects of many research works and studies but the results are seldom published.

This article is only an echaustive part of a paper [1] and represents an attempt to give some contribution to the extension of knowledge in the area of this very complex topic.

Adopted assumptions and values used to form the mathematical model

The above-mentioned paper [1] has defined the mathematical model for the simulation of underwater driving conditions. Because of the scope required to form the mathematical model, the mathematical models, refering to engine operation under special conditions, and given in [2 and 3] are used. When forming the mathematical model, we started from certain assumptions and values which were determined experimentally under laboratory conditions and which refer to engine and related devices operation in underwater driving conditions. Theoretical data from [2 and 3] were used for some values.

The hydraulic SCHENK brake was used to simulate loads in laboratory conditions.

The brake simulated loads that should be overcome by the engine during underwater driving, various terrain configurations and depths of water obstacles. The resistance at the outlet system was simulated by clappers fitted at the engine exhaust.

When making the mathematical model, as well as when determining certain values experimentally, we started from the following assumptions:

- a quasi-stationary model was applied;
- calculation is made only for characteristic path points, and the transition between the calculated points was accepted as linear;
- the flat section of the path when approaching a water obstacle is taken as a starting condition for the calculation (point 1, Fig. 1);
- the beginning of overcoming the water obstacle is point “1” (Fig. 1);
- during underwater driving, the tank moves at constant speed along the complete path;
- water obstacle is stagnant water (V = 0);
- variable resistance at the engine exhaust due to the exhaust clappers is not taken into account, air resistance is taken as the mean value of resistance during the cycle;
- operation process of all cylinders is carried out in the identical manner;
- the calculation of the operating cycle is not made when the driver uses the brake;

[1)] Military Technical Institute (VTI), Katanićeva 15, 11000 Beograd

- the quantity of heat eliminated by cooling the engine-transmission unit armour is equal to the quantity of heat required to heat engine-transmission unit and there is not rise of the engine temperature level when overcoming the water obstacle;
- the covers of the engine-transmission unit are closed;
- the cooling fan is turned on and it revolves in a closed space;
- the end of overcoming the water obstacle is actually the moment when the tank resumes the horizontal position after having passed the obstacle (point 26, Fig. 1).

Basic configuration of the calculated path

Figs.1 and 2 show the profiles of paths on entering (Fig.1) and exiting points (Fig.2) of the tank for which the calculation has been made. The basic data on the path are given in Table 1.

The path is relatively flat but steep at entering and exiting sections. The depth of water obstacle varies, the deepest being 3.25 m. Due to the changing configuration of the path when going under water or getting ashore, the engine loading also changes so the points of calculation were taken for each 0.5 m of the depth change.

Since the influence of the engine temperature change towards the transmission unit could be left out and based on the assumption adopted to form the mathematical model, there was no need to analyze the path section in more detail, i.e. to make calculations for more points.

Table 1. Numerical data on the path

Item No.	Path covered [m]	Ascent/ Descent [%]	Submersi-bility [%]	Depth of water [m]	F_{gus} [kN]	M_{mot} [Nm]
1	0	0	0	0	60.2	1534
2	1.4	-5	0	0	22.4	898
3	2.3	-10	0	0	-15.5	260
4	3.1	-15	0	0	-53.3	-376
5	7.0	-15	25	0	-47.3	-276
6	9.0	-15	50	0	-41.4	-176
7	10.7	-15	75	0	-35.4	-75.3
8	13.3	-15	100	0.5	-29.5	24.8
9	16.8	-15	100	1.5	-29.5	24.8
10	20.4	-15	100	2.5	-29.5	24.8
11	21.9	-10	100	2.8	-6.3	415
12	23.0	-5	100	3.5	17	807
13	27.0	0	100	3.75	40.2	1198
14	528.0	5	100	3.75	63.1	1583
15	529.4	10	100	3.5	85.7	1964
16	530.8	15	100	3.2	107.7	2334
17	535.1	15	100	2	107.7	2334
18	538.9	15	100	1	107.7	2334
19	540.2	15	75	0.6	123.3	2597
20	541.9	15	50	0.3	138.9	2859
21	542.7	15	40	0	144	2960
22	543.5	15	25	0	154.5	3122
23	547.6	15	0	0	170.1	3384
24	548.5	10	0	0	134.3	2777
25	549.5	5	0	0	97.6	2164
26	550.9	0	0	0	60.2	1534

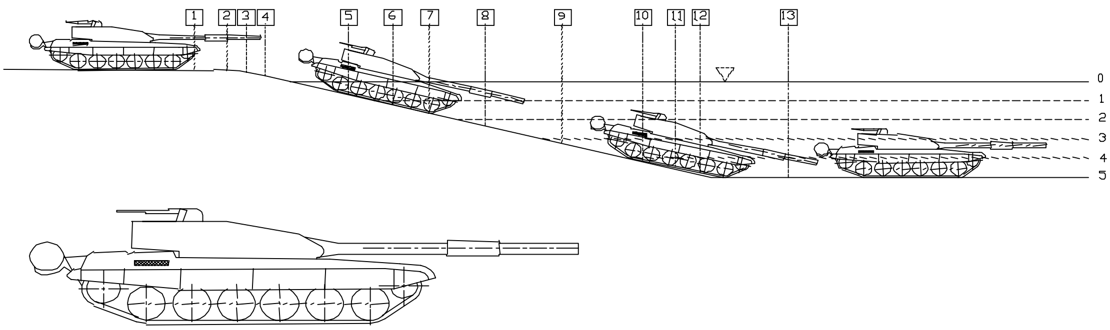

Figure 1. Tank entering the water

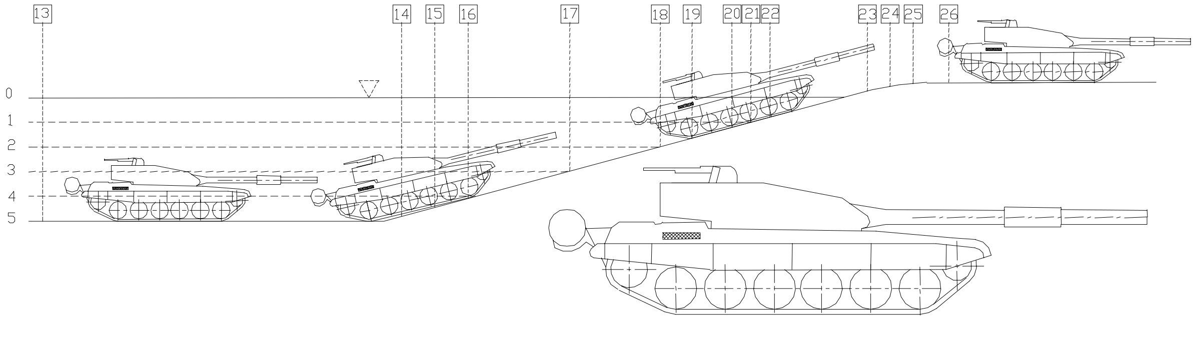

Figure 2. Tank going ashore

Basic values determined experimentally under laboratory conditions

By simulating certain modes of underwater driving in laboratory, the following values have been determined:

- M_{mot} - engine crankshaft moment;
- N - engine number of revolutions;
- T_O - environment temperature;
- T_G - fuel temperature in the flowmeter;
- T_{G1} - fuel temperature in the high-pressure pump (PVP);
- T_{G2} - temperature at the high-pressure pump verflow;
- T_{W1} - water temperature at the engine inlet;
- T_{W2} - water temperature at the engine outlet;
- T_{W3} - water temperature at the engine air suction inlet;
- T_{W4} - water temperature at the engine air suction outlet;
- T_3 - engine exhaust gas temperature;
- ΔP - pressure drop at the screen;
- P_{11} - sub-pressure in front of the compressor to the left;
- P_{1d} - sub-pressure in front of the compressor to the right;
- P_{21} - pressure behind the compressor to the left;
- P_{2d} - pressure behind the compressor to the right;
- $P`_{V2}$ - air pressure at the turbo-compressor inlet;
- P_{zmax} - maximum pressure in the cylinder;
- $P_{3.11}$ - exhaust gas pressure before the turbine in the first channel to the left;
- $P_{3.1d}$ - exhaust gas pressure before the turbine in the first channel to the right;
- $P_{3.21}$ - exhaust gas pressure before the turbine in the second channel to the left;
- $P_{3.2.d}$ - exhaust gas pressure before the turbine in the second channel to the right;
- $P_{4.1}$ - exhaust gas pressure behind the turbine to the left;
- $P_{4.d}$ - exhaust gas pressure behind the turbine to the right.

The results obtained applying the mathematical model

The mathematical model defined in [1] for the path shown in Figs.1 and 2 was used. The results are given as diagrams in Figs.3 to 9.

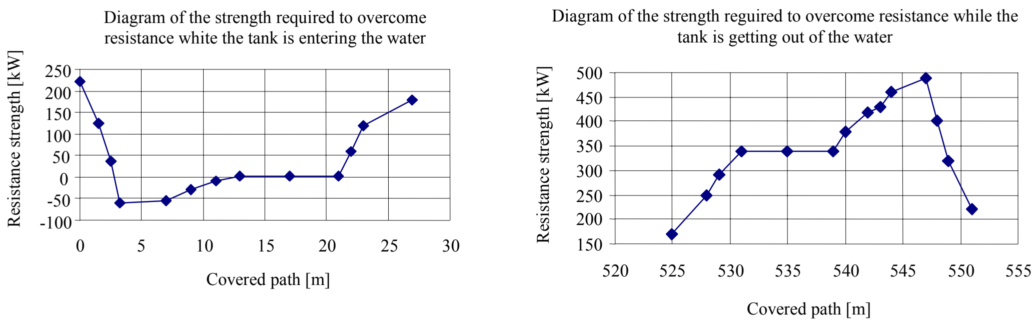

Figure 3. Diagrams of the resistance strength

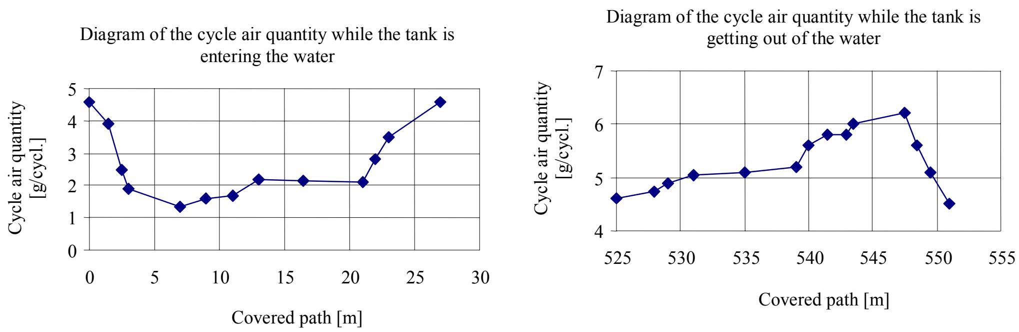

Figure 4. Diagrams of the cycle air quantity

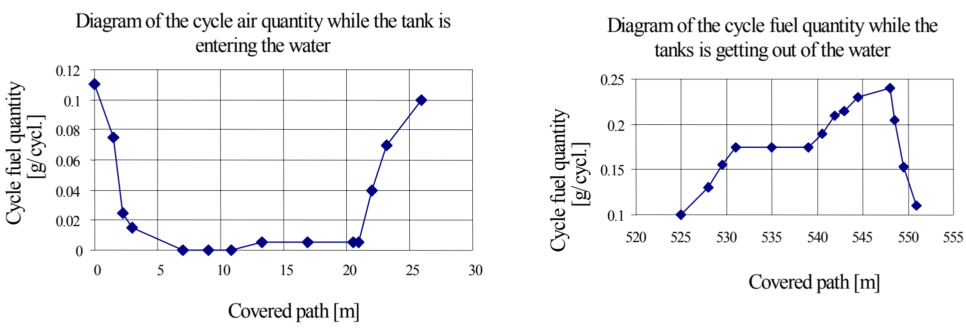

Figure 5. Diagrams of the cycle fuel quantity

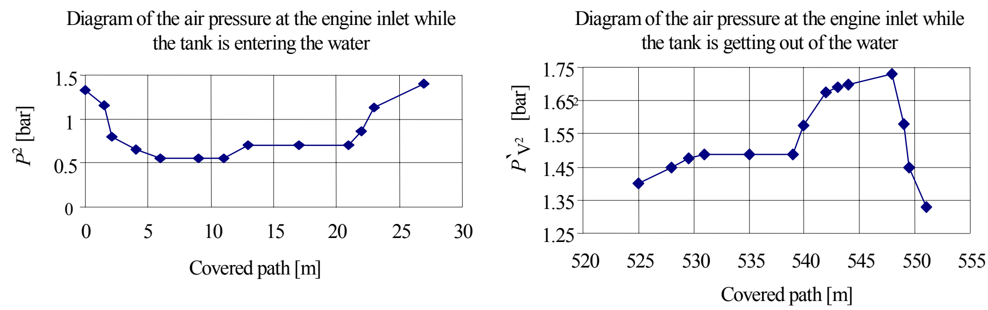

Figure 6. Diagrams of the air pressure at the engine inlet

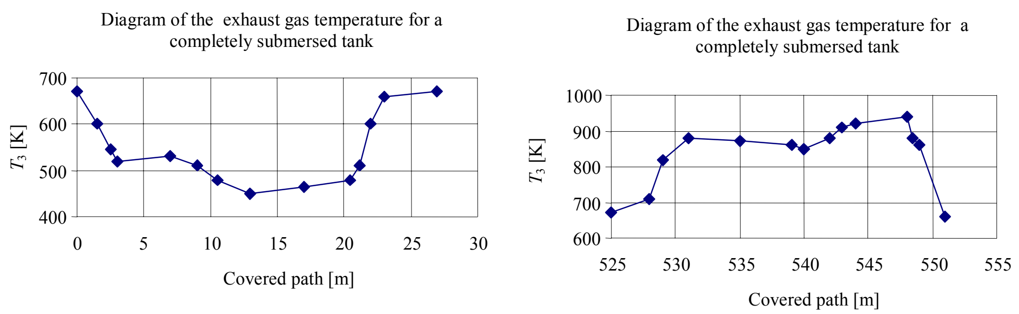

Figure 7. Diagrams of the exhaust gas temperature

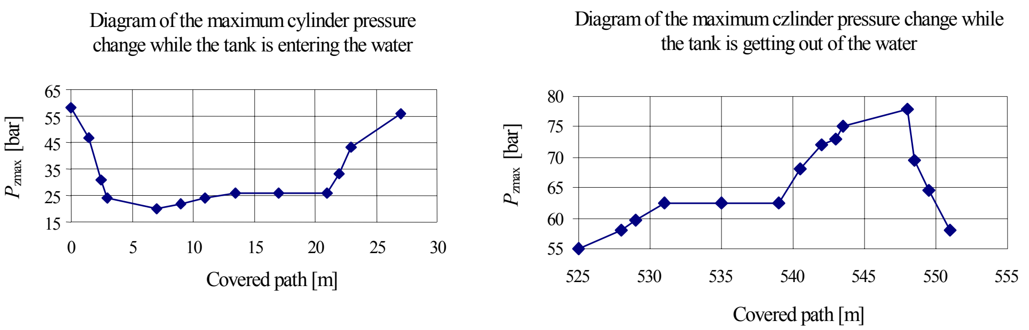

Figure 8. Diagrams of the maximum cylinder pressure change

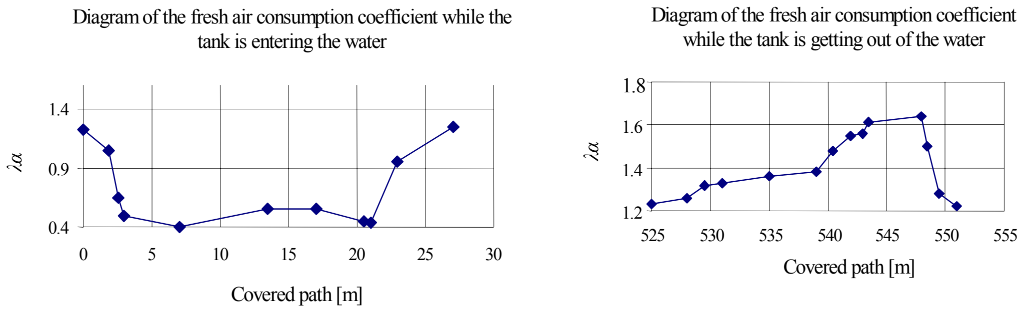

Figure 9. Diagrams of the fresh air consumption coefficient

Conclusion

Based on the obtained results, the following conclusions can be made:

Simulating the engine operation during underwater driving by means of the mathematical model from [1], we have obtained the results identical to or slightly differing from those published in the literature available in this field.

In order to be able to give a realistic evaluation of the used mathematical model, it is necessary to test a tank under real conditions and compare the obtained results.

The mathematical model has not included the specific characteristics of turbo-charged engines, which are mainly used in contemporary tanks. During underwater driving turbo-compressors operate under heavy conditions. The compressor operates with high suction attenuation while the turbine operates with high exhaust attenuation. In addition to thermo-dynamic problems regarding the compressor operation, this could lead to combustion and draining of oil from the turbo-compressor bearings, which could consequently lead to their jamming.

References

[1] IVOŠEVIĆ MILIĆ. Savlađivanje vodenih prepreka borbenim vozilima podvodnim kretanjem. Magistarski rad, Mašinski fakultet, 1997 god, Beograd.

[2] JANKOV RADOMIR. Matematičko modeliranje strujno-termodinamičkih procesa i pogonskih karakteristika dizel-motora. 1984 god, Naučna knjiga, Beograd.

[3] BRILING,N.R, VIHERT,M.M. Guterman I.I. Bistronodnie dizeli mašgiz. 1951 god.

Received: 10.10.2003

Neki parametri rada motora dobijeni primenom matematičkog modeliranja podvodne vožnje tenkova

U radu su navedene pretpostavke i eksperimentalno određene veličine u laboratorijskim uslovima koje su poslužile za formiranje matematičkog modela za simulaciju kretanja pri savlađivanju vodene prepreku podvodnom vožnjom. Navedeni su teoretski uslovi kretanja tenka. Primenom matematičkog modela za simulaciju podvodne vožnje tenka dobijeni su određeni parametri koji se odnose na rad motora, koji su prikazani u vidu dijagrama.

Ključne reči: **tenk, podvodna vožnja, motor, pritisak, gorivo, količina toplote, matematički model.**

Quelques paramètres du fonctionnement de moteur, obtenus par la modélisation mathématique de la conduite du char en plongée

L'article donne les suppositions et les valeurs déterminées expérimentalement en laboratoire qui servaient comme la base pour la formulation d'un modèle mathématique qui simule la conduite du char en plongée. Les conditions théoriques du mouvement de char sont également données. Les paramètres du fonctionnement de moteur, obtenus par le modèle, sont présentés en forme de diagrammes.

Mots-clés: **char, conduite en char, moteur, pression, carburant, quantité de chaleur, modèle mathématique.**