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The Advantages of Using Rotating Machines on the Transport of Fluids in Building Installations

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Abstract: A new construction solution for a rotating machine with two profiled rotors that can carry clean or polyphase fluids (water + ash, water + sand, etc.) is presented.
The operating principle is stated and the flow rate, the drive power and actual efficiency of this machine shall be determined.
Keywords: rotating volumetric pump, profiled rotors, effective efficiency.

I. INTRODUCTION

A classification of rotating machines that function as both work machines and force machines shall be provided.
According to their intended purpose, the machines are classified into two categories[1][2]:
1) Power machines (motor machines) that convert a certain form of energy into mechanical energy; for example: internal combustion engines, steam turbines, gas turbines, etc.
2) Working machines that convert mechanical energy into another form of energy, for example: pumps, fans, compressors.

The research aims to build machines to ensure the transformation of the engine moment received from the shaft into useful effects, but with the lowest possible energy losses [1].

Both power and working machines are traversed by fluids; according to the flow variation parameters, it is classified as follows:
a) Hydraulic machines that drive or are driven by fluids, neglecting thermal phenomena.
b) Thermal machines that carry gases or vapors (or are driven by them) in which the thermal processes that occur cannot be neglected.

From the class of hydraulic working machines, the present paper deals with a rotating volumetric pump.
According to the operating principle, the pumps can be classified into two categories:
- Volumetric pumps (with piston, with blades, with profiled rotors).
- Non-volumetric pumps (centrifugal pumps, axial pumps).

A type of rotating working machine with profiled rotors is presented; it can work as [1], [2]:
- ➢ A fan, for driving different gas mixtures with or without suspensions;
- ➢ A low pressure compressor;
- ➢ A rotating volumetric pump for the conveyance of any type of liquid or gas fluid, namely:
- ➢ General fluids: water, air, steam, etc.
- ➢ Multiphase fluids: water + air, water + sand, water + ash etc.
- ➢ Viscous fluids: oil, diesel, petroleum, etc.

The advantage of the rotating working machine is that the entire torque received from the drive motor is used to transport the fluid.

II. PRESENTATION OF THE CONSTRUCTIVE SOLUTION AND THE PRINCIPLE OF OPERATION OF THE ROTATING MACHINE

The rotating volumetric pump with profiled rotors is composed *(figure 1*) of two profiled rotors (2), (5), which rotate at same speed inside a case (1), (4); the profiled rotors are engaged by two gear wheels, thus ensuring their synchronization. The gear wheels are mounted on the outside of the pump, on the shafts (7), (9) of the two rotors.

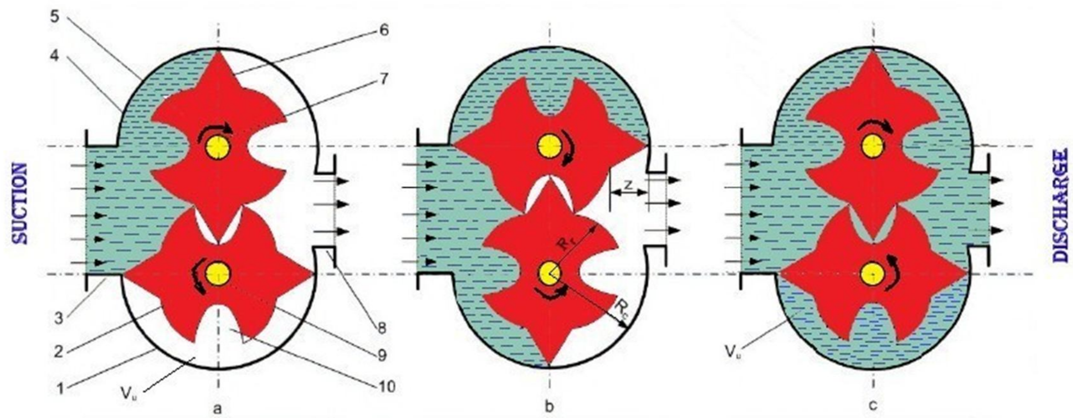

Fig. 1: Position of the rotors after a 90° rotation
1 - lower case; 2 - lower rotor; 3 - the suction chamber; 4 - upper case; 5 - upper rotor;
6 - rotating piston; 7 - driven shaft; 8 - discharge chamber; 9 - driving shaft; 10 - cavity in which the piston of the upper rotor enters

The fluid entering in the suction chamber (3) is transported to the discharge chamber (8) (figure 1) by the rotating pistons (6); this occurs even if the fluid contains solid particles or is viscous. Figure 1 (a, b, c) shows the fluid flow after a 90° rotation of the two rotors.
The determination of the shape of the contour of the two rotors is performed on the basis of calculation programs [3] [4], and the construction of the rotors takes place on a numerically controlled center (CNC) [5] [6].

III. ESTABLISHING OF THE CALCULATION FORMULA FOR THE FLOW RATE TRANSPORTED BY THE MACHINE

After a rotation by 180 °, the fluid in the useful volume V_u (Fig.1, c), i.e in the space between the pistons, the lower casing (1) and the lower rotor (2), will be sent to the discharge chamber. At a complete rotation of the shaft (9) two such volumes will be transported from the suction to the discharge [7] [8]:

$$\dot{V}_u = 2\left(\frac{\pi R_c^2}{2} - \frac{\pi R_r^2}{2}\right)\cdot l \quad [\mathrm{m^3/rot}] \tag{1}$$

The casing radius (R_c) is computed as sum of the rotor radius (R_r) and of the piston height (z):

$$R_c = R_r + z \quad [m] \tag{2}$$

Relations (1) and (2) lead to:

$$\dot{V}_u = \pi l z (z + 2R_r) \quad [\mathrm{m^3/rot}] \tag{3}$$

The volumetric flow rate discharged by a single rotor of length l [m] and speed n [rpm] will be equal to:

$$\dot{V}_u = \pi l z (z + 2R_r)\frac{n_r}{60} \quad [\mathrm{m^3/s}] \tag{4}$$

Because the machine has two identical rotors, the fluid flow rate transported by the machine will be equal to:

$$\dot{V}_m = 2\dot{V}_u = \pi l z (z + 2R_r)\frac{n_r}{30} \quad [\mathrm{m^3/s}] \tag{5}$$

It can be noticed from (5) that the flow rate transported by the pump is directly proportional with l, Rr, n and the square of z.

IV. ESTABLISHING OF THE CALCULATION FORMULA FOR THE DRIVING POWER OF THE ROTATING MACHINE.

The theoretical driving power of the machine is given by the relation [1]:

$$P = \dot{V}_m \cdot \Delta p \quad [W] \tag{6}$$

where Δp is the increase in pressure achieved by the machine between suction and discharge [N/m^2]; replacing Δp with:

$$\Delta p = \rho_{H_2O} \cdot g \cdot H_g \quad \left[N/m^2\right] \tag{7}$$

results :

$$P = \dot{V} \cdot \rho_{H_2O} \cdot g \cdot H_g = \pi l z (z + 2R_r) \cdot \frac{n_r}{30} \cdot \rho_{H_2O} \cdot g \cdot H_g \quad [W] \tag{8}$$

where H_g is the charge of the pump expressed in (mH_2O).
It is observed that P = f (l, z, Rr, nr, *p*, Hg).

V. DIAGRAM OF THE EXPERIMENTAL INSTALLATION

After the construction of the prototype of the rotating volumetric machine, an experimental installation was designed to tase it.
The experimental installation presented in figure 2 is made in open circuit being conceived, designed and built in the laboratory of the Department of Thermotechnics, Engines, Thermal and Refrigeration Equipment from the Polytechnic University of Bucharest, in order to validate the theoretical results.

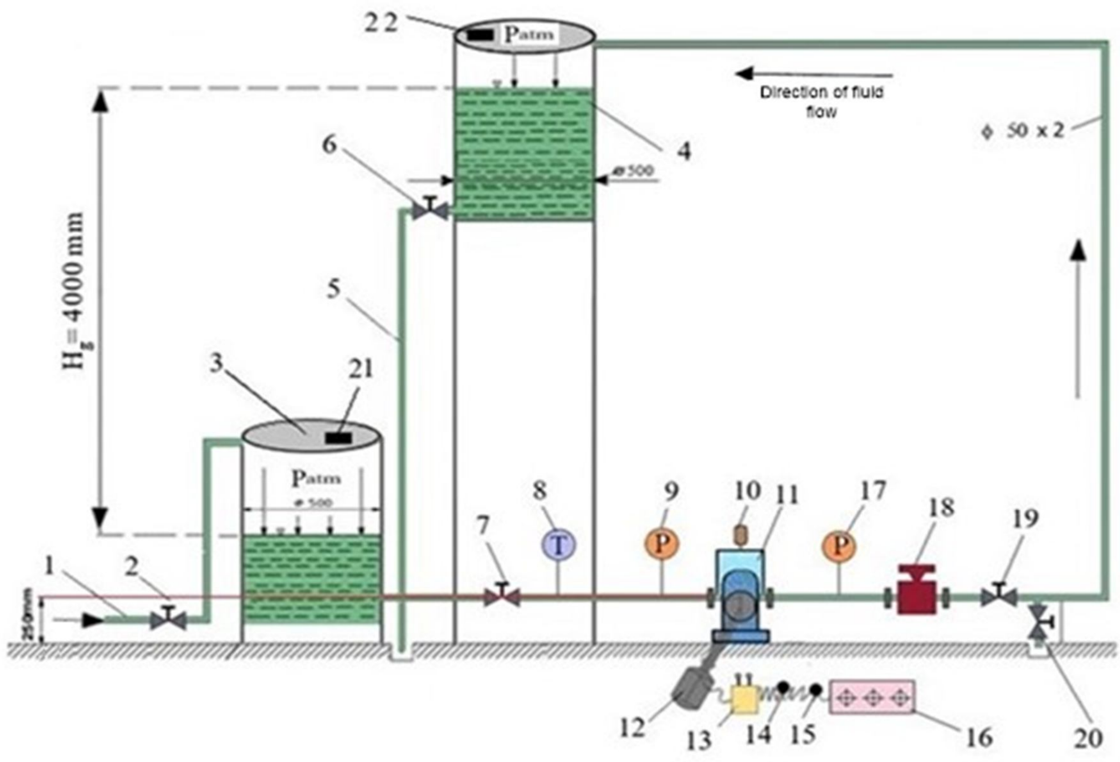

Fig 2. The sketch of the experimental installation
1-pipe; 2 - tap Dn 60 Pn 2 bar; 3 - water tank; 4 - discharge tank; 5 - pipe for emptying the tank with water; 6 - drain tap; 7 - valve Dn 60 Pn 2 bar; 8 - thermometer; 9 - pressure gauge at pump suction; 10 - pump suction manometer; 11 - rotating volumetric pump; 12 - the electric motor of the pump; 13 - frequency converter;
14 - ammeter; 15 - multimeter; 16 - 380 V alternating current source; 17 - manometer at pump discharge;
18 - electromagnetic flow meter; 19 - flow control valve; 20 - drain valve; 21 - 22 - air vent.

The experimental installation consists of a tank (3) from which the working fluid is aspired in by a rotating volumetric pump with profiled rotors (11); at the outlet of the rotating machine the water pressure is measured with the manometer (17). The fluid flow rate transported by the rotating machine is recorded on the screen of the electromagnetic flow meter (18) the water reaching the tank (4) through the plexiglass pipe with nominal diameter Ø 50x2.
The valve (19) has been to regulate the flow rate of fluid transported through the circuit, in order to achieve the load characteristic.
Measurements are made at various speeds of the electric motor; with the help of the frequency converter allows the measurement and adjustment of the speed of the electric motor.

VI. RESULTS OF EXPERIMENTAL RESEARCH AND THEIR PROCESSING

A. Experimental results for $\dot{V} = f(n_r)$

By changing the speed, the flow rate transported by the rotating machine was also changed; by means of the electromagnetic flow meter, the flow rate transported through the experimental installation was measured.

The results from the theoretical calculations ($\dot{V}_t$) and experimental results ($\dot{V}_r$) the data in Table 1 are obtained.

Table 1.

Theoretical And Experimental Values OF $\dot{V} = f(n_r)$

n_r [rpm]	100	200	300	400	500
$\dot{V}_t\left[m^3/s\right]$	0,001966	0,003932	0,005898	0,007864	0,009830
$\dot{V}_r\left[m^3/s\right]$	0,00180	0,00363	0,00553	0,00747	0,00923

Based on the data in table 1, the function $\dot{V} = f(n_r)$ in figure 3 was plotted.

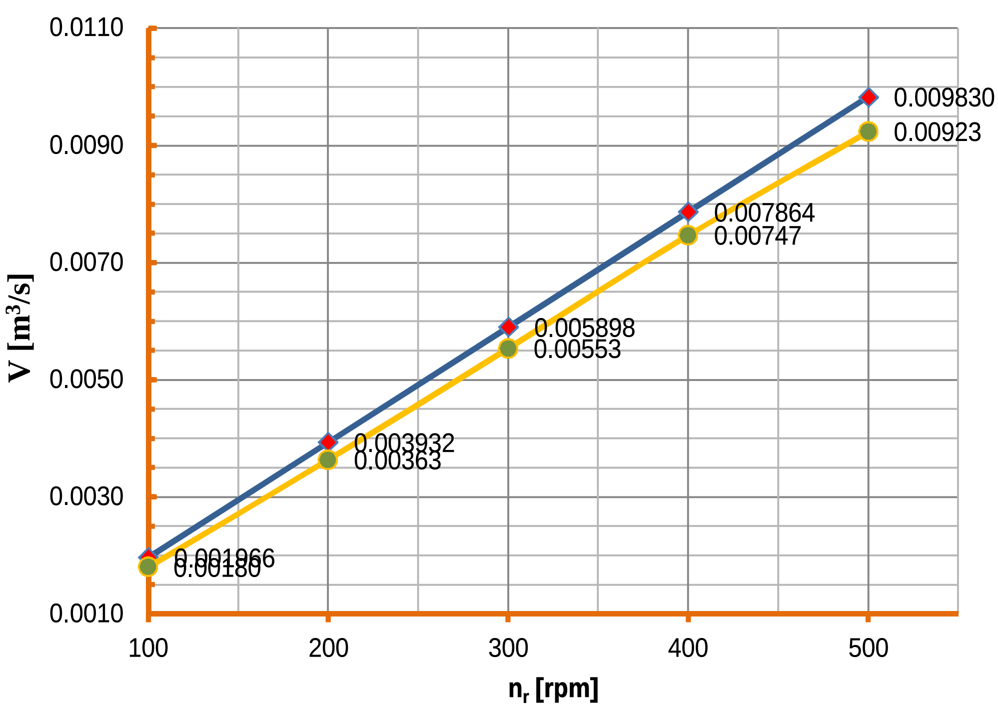

FIG. 3. Graphs of the function $\dot{V} = f(n_r)$

$\dot{V}_t$ - the theoretical flow rate transported by the rotating machine; $\dot{V}_r$ - the actual flow rate.

Figure 3 shows that the two graphs are very close; thus, the volumeetric efficiency will be:

$$\eta_v = \frac{\dot{V}_t}{\dot{V}_r}[\%] \tag{9}$$

Performing the calculations resulted in Table 2 the values of the efficiency at different speeds of the rotating machine.

TABLE 2.
VOLUME EFFICIENCY VALUES BY MACHINE SPEED

n_r [rpm]	100	200	300	400	500
η_v	0,916	0,924	0,938	0,949	0,939

Based on the data in Table 2, Figure 4 shows the graph of yield variation at different speeds rotation machine.

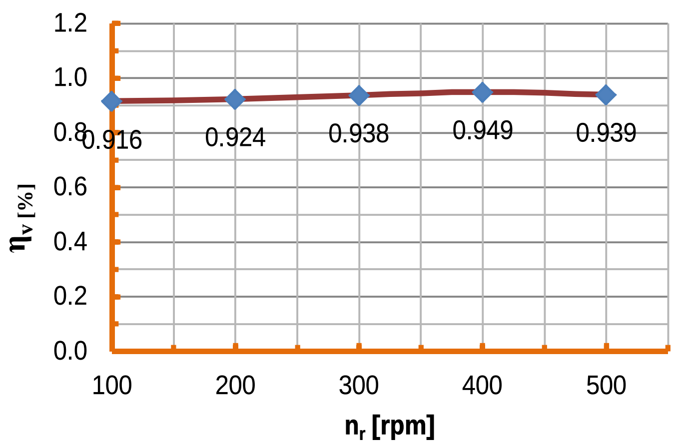

Fig. 4. Graphic representation of the function $\eta_v = f(n_r)\frac{1}{2}$

Figure 3 shows that as the speed increases above a certain speed value $n_r \geq 400[rot/\min]$, the value of the efficiency will decrease as volume losses increase.

B. *Experimental results for P = f (n_r)*

The electrical voltage (U) and the intensity of the electric current (I) were measured for at the rotational speed variation.

The active power absorbed by the electric motor (P_{me}) is calculated taking into account the efficiency of the power at the electric motor torque is calculated by the relation (P_{cm}).

$$P_{c,m} = P_{m,e} \cdot \eta_{m,e} \quad [W] \tag{10}$$

Subsequently, the power to the torque of the machine (P_{cm}) is subtracted from the power to overcome the hydrostatic load of the pump and the linear and local hydraulic resistances ($P_{\Delta p}$) located on the system circuit.

Where η_{me} is the effective efficiency of the electric motor.

The actual efficiency of the rotating machine is determined by the linear, local pressure losses and the electric power absorbed by the electric motor. Thus, the electric power absorbed by the electric motor is determined.

$$P_{m,e} = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi \quad [W] \tag{11}$$

From the catalog of the electric motor factory, for the chosen motor are given:

- electric motor efficiency: $\eta_{m,e} = 0,747$;
- power factor: $\cos\varphi = 0,71$.

The effective efficiency of the volumetric pump will be:

$$\eta_e = \frac{P_H + P_{\Delta p}}{P_{cm}} \quad (12)$$

$P_H = \dot{V} \cdot \Delta p_H = 4{,}08 \cdot 10^{-3} \cdot 14715 = 60 \quad [W]$

Linear pressure losses are given by the relation [4] :

$$\Delta p_{lin} = \lambda \frac{l}{d} \rho \frac{w^2}{2} \left[N/m^2 \right] \quad (13)$$

$$\left.\begin{array}{l} \mathrm{Re} = \dfrac{wd}{\nu} = \dfrac{2{,}68 \cdot 0{,}044}{1{,}04 \cdot 10^{-6}} = 1{,}13 \cdot 10^5 \\ \\ \dfrac{d}{\varepsilon} = \dfrac{44}{0{,}03} = 1466 \end{array}\right\} \Rightarrow \lambda = 0{,}021 \quad (14)$$

$$\Delta p_{lin} = 0{,}021 \frac{6}{0{,}044} 1000 \frac{2{,}68^2}{2} = 10283{,}89 \quad \left[N/m^2 \right] \quad (15)$$

The power consumed to overcome the linear hydraulic resistances will be:

$$P_{lin} = \dot{V} \cdot \Delta p_H = 4{,}08 \cdot 10^{-3} \cdot 10283{,}89 = 42 \quad [W] \quad (16)$$

Local pressure losses are calculated by the relation: [6]

$$\Delta p_{loc} = \sum_{i=1}^{n} \xi_i \rho \frac{w^2}{2} \quad \left[N/m^2 \right] \quad (17)$$

$$\sum \xi_i = \xi_{aspirat.pompă} + 3\xi_{\cot 90^\circ} + \xi_{debitmetru} + 2\xi_{robinet} \quad (18)$$

From [6] it follows:

$$\sum \xi_i = 1{,}6 + 3 \cdot 0{,}3 + 2 \cdot 1 + 2 \cdot 1 = 6{,}6 \quad (19)$$

$$\Delta p_{loc} = 6{,}6 \cdot 1000 \cdot \frac{2{,}68^2}{2} = 23701{,}92 \quad \left[N/m^2 \right] \quad (20)$$

The power consumed to defeat the local resistance will be:

$$P_{loc} = 4{,}08 \cdot 10^{-3} \cdot 23701{,}92 = 96{,}7 \quad [W] \quad (21)$$

The total power to overcome the hydraulic resistances (linear + local) will be:

$$P_{\Delta p} = P_{lin} + P_{loc} = 42 + 96{,}7 = 138{,}7 \quad [W] \quad (22)$$

The actual efficiency of the rotating machine will be:

$$\eta_{ef} = \frac{P_H + P_{\Delta p}}{P_{cm}} = \frac{60 + 138{,}7}{264{,}93} = 0{,}75 \quad (23)$$

On rotating machines, the actual efficiency (η_{ef}) has values between $0{,}50 \ldots 0{,}80$.

The energy balance of the installation will be:

$$P_{cm} = 264{,}93 \quad [W] \left| \begin{array}{l} P_H = 60 \quad [W] \\ \\ P_{\Delta p} = 138{,}7 \quad [W] \\ \\ P_f = 66{,}23 \quad [W] \end{array} \right. \quad (24$$

where P_f is the power consumed by the viscous friction between the rotors and the housing, calculated as the difference:

$$P_f = P_{c,m} - (P_H + P_{\Delta p}) = 264,93 - (60 + 138,7) = 66,23 \quad [W] \tag{25}$$

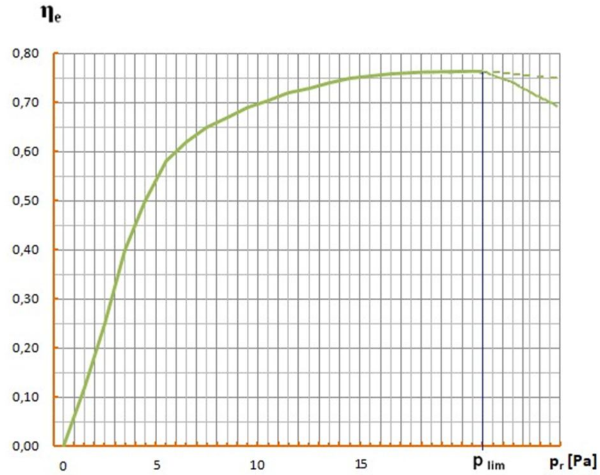

Fig. 5. Yield characteristic: $\eta = f(p_r)$

For the efficiency characteristic represented in general in Figure 5, it is observed that the value of the pump efficiency (η_{ef}) increases until reaching the value (p_{lim}) and subsequently decreases as a result of the decrease η_v and η_m.

VII. CONCLUSIONS

A. The new type of rotating machine guarantees a high volumetric efficiency, in the range of 0.75-0.85, values that coincide with the ones presented in technical literature [7];

B. The machine is able to transport any fluid substance: used water, oil products, polyphase fluids, rheological fluids;

C. The paper presents original aspects regarding the constructive solution as well as the computation relations that describe the functioning and the performances of the machine.

D. The constructive solution is simple and can be used for the transport of oil products. The pump can be used for the transport of waste waters and of polyphase fluids.

E. The pump can be easily achieved because the manufacturing technology of the rotors and casing is based on a CNC program; the parts are manufactured on a CNC centre.

F. This type of rotating machine has real advantages compared to other types of profiled rotor machines.

The paper points out that the development of a technical solution must take into account:

1) Increased efficiency of the installation;

2) Increased reliability;

3) A wide range of operations;

4) The value of the investment should be as small as possible.

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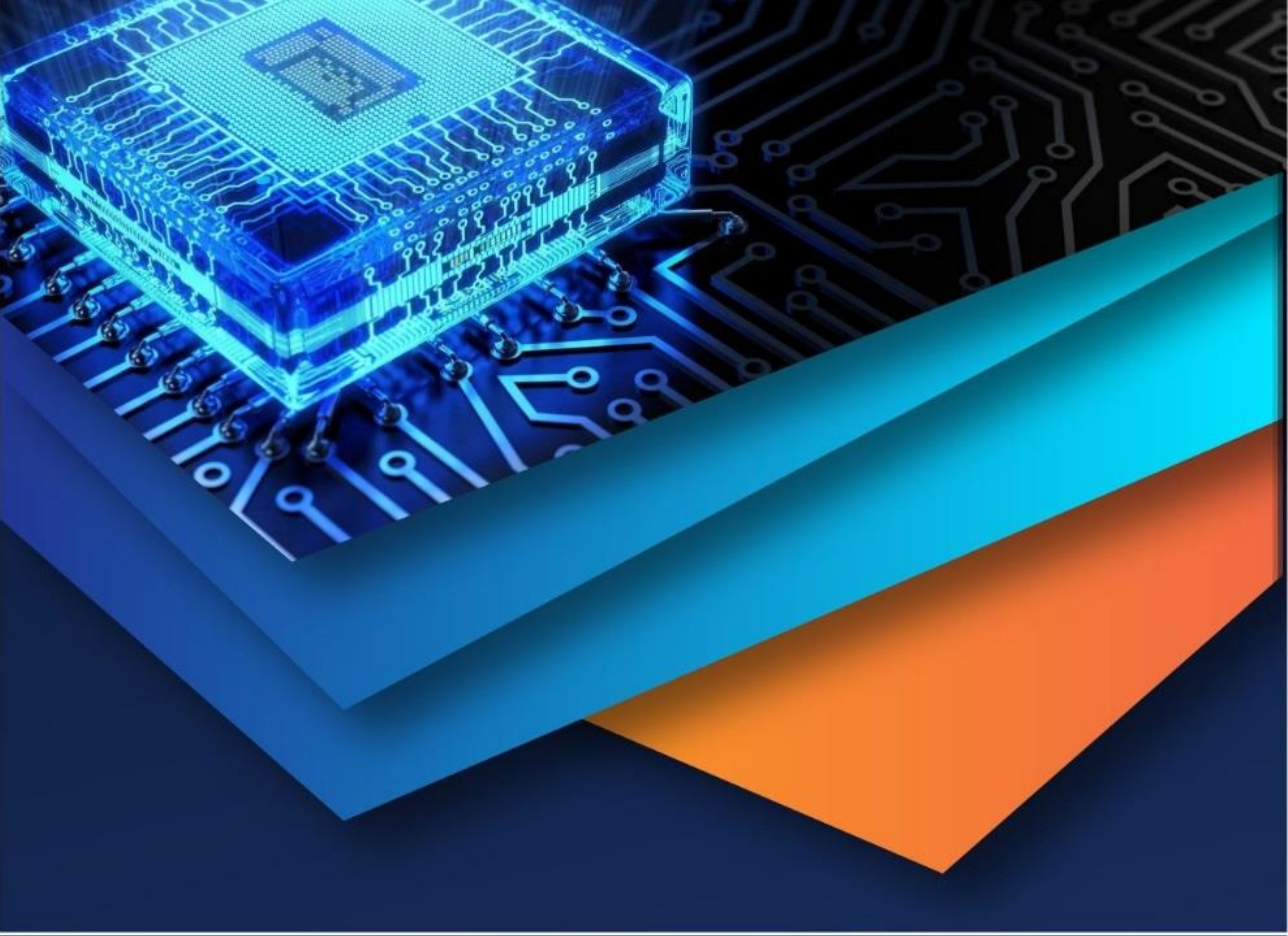

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