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CONSIDERATIONS ON IMPROVING THE EFFICIENCY OF IRRIGATION SYSTEMS BY USING OF ELECTRIC PUMPS WITH ADJUSTABLE ROTATIONAL SPEED

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Abstract: *Water consumption management in modern agriculture influences crop yields and the long-term sustainability of traditional irrigation systems. These contain pumps driven by fixed-rotational speed electro motors or fixed-rotational speed heat engines, powered by gasoline or diesel. Traditional solutions, which ensure the basic supply of water for irrigation, have the following disadvantages: high energy consumption, limited adaptability, frequent wear and tear of irrigation equipment. For agricultural areas that face seasonal variations in water demand, a fixed-rotational speed pump cannot effectively regulate its power, which leads to energy waste and a reduction in the life of the irrigation equipment.*

These disadvantages can be eliminated by controlling the frequency and voltage supplied to the electric motor driving the pump. In this way, the pump rotational speed can be adjusted in real time, so that the water flow supplied corresponds to the actual needs of the irrigated area. The adjustable pump, driven by a variable frequency electric motor, reduces the energy consumption of the irrigation system in which it is integrated and allows precise irrigation programming, saving water resources.

The authors present the advantages of using adjustable pumps in agricultural irrigation systems and the schematic diagram of an experimental stand that demonstrates these advantages.

Keywords: *Water consumption management, adjustable pump, variable frequency electromotor, irrigation system*

1. Introduction

Variable rotational speed pumps (also known as inverter or variable rotational speed drives – VFD) are playing an increasingly important role in modern irrigation systems, due to the technical, economic and sustainability advantages they provide. They ensure:

- *energy efficiency*, by adjusting the rotational speed according to the actual water demand, which reduces energy consumption and eliminates the high energy losses caused by constant operation at maximum power of fixed rotational speed pumps;
- *constant and stable pressure*, which is essential for correct water distribution in the irrigation process. Variable rotational speed pumps adapt immediately to changes in flow rate (opening or closing of irrigation sectors);
- *longer equipment life*. Sudden starts and stops of pumps are reduced, which means less mechanical and hydraulic shocks on pipes, sprinklers and solenoid valves. At the same time, wear on the drive motor and pump components is significantly reduced;
- *flexibility in operation.* The same irrigation system can serve different crops, with variable flow and pressure requirements. In this way, water resources are used more efficiently during periods of low consumption (partial watering, drip irrigation, etc.);
- *reduction of operating costs*. Energy bills are lower, maintenance and repair costs are reduced, the lifespan of the entire irrigation system increases.

2. The importance of variable frequency drive of electric pumps in irrigation systems

Variable frequency drives (VFDs) provide high-performance, energy-efficient electric motor control for a wide range of industrial [1] and agricultural applications. They allow precise rotational speed control of electric pumps, easy start/stop and significant energy savings. With nominal powers from 0.75kW to 500kW, they are ideal for pumps, fans, conveyors and automation systems.

By varying the frequency of the current, the VFD performs:

- *control of the increase or decrease of the pump motor rotational speed*, respectively controlling the water flow rate supplied;
- *regulation of voltage levels*, respectively optimizing the operation of the electric motor and preventing energy waste;
- *elimination of sudden surges* at start-up by gradually increasing/decreasing the voltage, a method that allows smooth acceleration, minimizing wear and protecting pipes from pressure shocks.

2.1 Variable Frequency Drive of Electric Pumps for Agricultural Irrigation

Variable frequency drive brings the following benefits to agricultural irrigation:

- *water efficiency irrigation water*: requirements fluctuate daily and seasonally. With a VFD, the rotational speed of the electric pump, and thus the flow rate delivered, can match crop requirements, avoiding excess water waste;
- *energy savings*: instead of operating at maximum capacity, the pump consumes only the amount of electricity needed, thus reducing operating costs and extending the life of the irrigation equipment;
- *system protection:* overheating, overcurrent and voltage fluctuations can damage pumps. VFDs integrate protection functions to ensure long-term stability.

Variable frequency electric pumps are essential for irrigation water distribution systems; by combining precise control of the electric motor with dedicated pump operation, water delivery can be optimized under various field conditions.

Energy efficiency and cost reduction are required by the constant maximum rotational speed of traditional electric pumps, consuming unnecessary energy even when water demand is low. A VFD electric pump adjusts the flow rate according to *soil moisture* and *crop requirements*, significantly reducing electricity bills. For farms that rely on *solar or hybrid energy systems*, VFD electric pumps perfectly align with variable energy inputs, ensuring uninterrupted irrigation.

Variable frequency electric pumps ensure the seasonal adaptability of the irrigation system. At the beginning of the planting season, when crops require less water, the pumps operate at reduced capacity, reducing unnecessary energy consumption. During hot and dry months, the system can increase production instantly, without overloading, ensuring peak water demand.

Water demand for irrigation is not constant. It changes with the season, time of day, and crop type. A VFD-controlled electric pump can automatically respond to these variations, *providing constant flow in drip irrigation, high-volume delivery for sprinklers, or controlled pressure for greenhouse systems*. This adaptability prevents both *over*- and *under-irrigation*, protecting crops and soil health.

Constant operation at high rotational speeds causes pumps and motors to wear out faster. By operating at variable rotational speeds, a VFD-controlled electric pump reduces mechanical stress, resulting in longer equipment life and lower maintenance costs. This translates into fewer repairs, less downtime, and higher productivity during critical periods of plant growth.

The smooth start and stop of VHD electric pumps prevent water hammer in pipes, protecting valves and pipe joints. When equipped with VFDs, electric motors are started and stopped smoothly, with gradual acceleration and deceleration, protecting irrigation infrastructure. Even when multiple sectors are opening or closing, VFD-controlled electric pumps maintain a constant pressure.

Solar integration: Many modern farms combine solar energy systems with VFD pumps. The adaptability of VFDs to power fluctuations makes them ideal for off-grid or hybrid energy applications.

Voltage stability: If local grids experience frequent fluctuations, a robust VFD with integrated protection functions is essential to prevent motor damage.

2.2 Practical applications in agriculture of VHD controlled electric pumps

The main practical applications in agriculture of VFD-controlled electric pumps are:
- *drip irrigation,* which provides precise water delivery at low pressure, optimized by VFD-controlled flow;
- *greenhouse irrigation*, which provides consistent water distribution for controlled environments. Controlled microclimates benefit from precise water dosing, specific to sensitive crops;
- *small-scale farm and orchard irrigation*, where pumps must adapt to fluctuating irrigation schedules;
- *large-scale field irrigation* with high-power VFD pumps, which can support water transport over long distances with stable pressure. Large fields benefit from uniform coverage, preventing dry areas and waterlogging. By aligning irrigation to the actual needs of crops, farmers ensure that they achieve *optimal soil moisture levels*, while conserving limited water resources. Over-irrigation not only wastes water, but can also damage soil structure and plant root systems. A VFD-controlled electric pump allows for precise water delivery and maintains stable pressure in drip lines, sprinklers, or pivot irrigation systems.

The correct selection of the VFD and electric pump required for a specific agricultural irrigation application is based on a clear assessment of: the *daily water* requirement; *the irrigation method* used; the available *water source*; *the flow rate and service pressure* required by the consumers of the irrigation system; *the distance and altitude of the consumer* furthest from the water source (the most disadvantaged consumer).

For modern farmers, a variable frequency electric pump is not only a technical upgrade but also a strategic investment, improving productivity while conserving vital resources.

For solar farms, VFD-equipped electric pumps offer unparalleled compatibility with fluctuating power availability. Farms that integrate solar panels with VFD electric pumps benefit from a more consistent and efficient use of renewable energy sources. This optimization leads to substantial savings; energy consumption is reduced by 20-40% compared to fixed-rotational speed pumping systems. *The evolution of agricultural irrigation is no longer about simply moving water from one place to another. Today, it is about delivering the right amount of water, at the right time, with maximum efficiency and reliability, and variable frequency drives (VFD) and VFD pumps make this possible. By adjusting motor rotational speed and pump performance, VFD technology allows irrigation systems to operate in harmony with field requirements in real time.*

3. Demonstration stand for testing a pumping group for agricultural irrigation

The authors propose to create a test stand for a pumping group intended for agricultural irrigation, consisting of two identical centrifugal electric pumps, coupled in parallel. One of the electric pumps is *fixed*, to ensure the *constant water needs* (*at low, medium and high loads*) of the irrigation system, and the other is *adjustable*, to ensure the water effectively distributed to the plants (*at low and medium loads*), during the irrigation process.

3.1 Basic scheme of the stand

The stand, with the schematic diagram in Figure 1, works as follows:
The electric pump **1** with adjustable flow, coupled in parallel with the electric pump **2** with fixed flow, sucks water from the tank **11**, equipped with the drain valve **13**, through the common collector **9**, and discharges water into the same tank through the common collector **10**. On the discharges of the two pumps, one-way valves **4** and **7** are provided, respectively, and on-off separation valves **3** and **5**, respectively **6** and **7** are provided on the suction/discharge pipes of the pumps. The load (required pressure) of the irrigation system is simulated with the control valve **12**, operated by the **SM** servomotor. The parameters measured during the experimental tests are: the pressures on the discharges of the two pumps, measured with the pressure transducers **T_{P1}** and **T_{P2}** and the

manometers **M_1** and **M_2**; the *flow rates* provided by the two pumps, measured with the flow rate transducers **T_{Q1}** and **T_{Q2}**, respectively; *the vibrations* of the two pumps, measured with the acceleration sensors **a_1**, **a_2**, mounted on the pump housings. The electrical and control cabinet **14**, in which the control module contains a programmable logic controller and a single-board computer, ensures: power supply to the motors of the electric pumps **1** and **2**; *control* of the frequency converter of the adjustable electric pump **1**; *control* of the valve servomotor **12**; acquisition of the hydraulic parameters (pressure and flow rate) of the two electric pumps and monitoring of their vibrations.

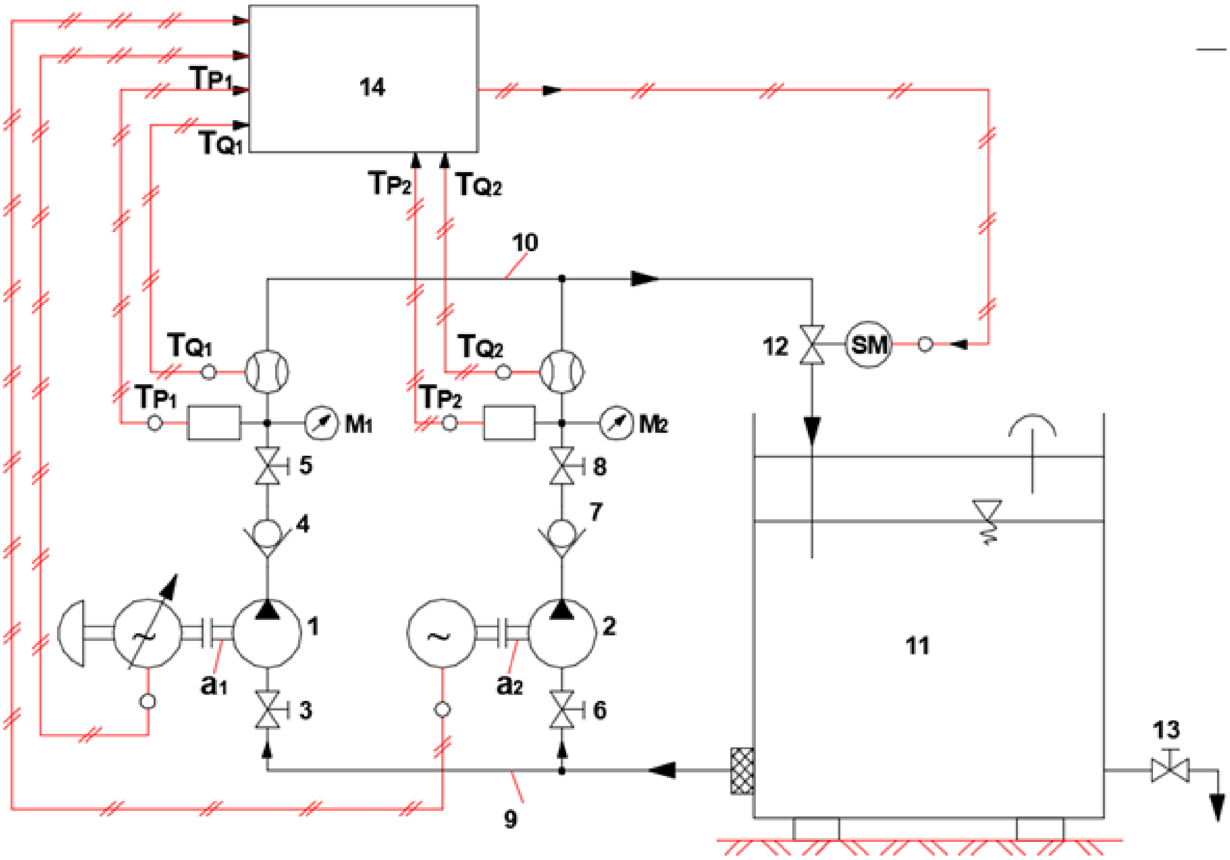


Fig. 1. Basic scheme of the stand

Minimal technical characteristics of the main components from the basic scheme of the stand are:
- for the electric pumps 1 and 2

Table 1: Flow rate Q and pumping height (according to technical data sheet of the electro pump [2])

Q (m^3/h)	0	1,5	3	6	9	12
Q (l/min)	0	25	50	100	150	200
H (m)	72	70	68	60	52	39

Suction nominal diameter *DN = 1 ¼"*; Discharge nominal diameter *DN = 1"*
Induction triphasic electrical engine for pump drive: 2 pols, 230/400 V, rotational speed n=2850 rev/min, nominal power = 4 kW, current intensity = 7A.
- for tank: volume = 1000 l; equipped with water filtration elements and filling cock /purge DN 25.
- for the variable frequency drive (variable rotational speed drive): Nominal supply voltage = 3x380...480 V - 15...10 %; Supply frequency = 50...60 Hz - 5...5 %; Engine power = 7,5 kW – normal usage; 5,5 kW – intense usage; communication port protocol Serial Modbus/RS485.

- for programmable automatic: Inputs number / Digital outputs = 24; Supply voltage = 24 V DC; Inputs module/Analog outputs = 2 pieces 2 x 4 - 8 analogue inputs, 2 x2 - 4 analogue outputs.
- for single board computer (Single Board Computer - SBC): Raspberry Pi 5/8GB; box Raspberry Pi 5 track DIN ABS; supplier 27W with USB-C for Raspberry Pi 5; battery RTC for Raspberry Pi 5; adaptor cable from Micro-HDMI to HDMI Black (A/M), 1 m; radiator case for Raspberry Pi 5 (black, with dual fan); Raspberry Pi Active Cooler; memory card SanDisk Extreme microSDXC 256GB,until at 190MB/s & 130MB/s Read/Write s A2 C10 V30 UHS-I U3.
- for pressure transducers: Measurement range = 0…10 bar; Supply voltage = 24 V DC; Current outputs = 4…20mA.
- for manometers: Measurement range = 0…10 bar; Dial diameter = 100 mm; Stainless steel case with glycerine (antivibration), radial (vertical mounting).
- for flow transducers: Measurement range = min 0,5 m^3/h, max 18 m^3/h; Supply voltage = 220 V AC, la 50 Hz; Maximum pressure =16 bar; Output voltage = 4…20 mA; Nominal diameter DN 25 mm; Communication protocol Modbus RTU / RS48.
- for accelerometers: supply = 1.71… 3.6 V; interface I2C (max. frequency 100KHz) and SPI (max. frequency 10MHz); automat standby function; it can be selected between ±2g/±4g/±8g/±16g.

3.2 Calculation of the collectors diameters and flow variation

For the pumping group made from two centrifugal pumps the collectors diameters and variations intervals of the flow are computed.

3.2.1 Diameters calculation

Both pumps extract water from the tank through the same suction collector and feed the tank through the same discharge collector. The collectors diameters of the pumping group formed by pumps coupled in parallel are calculated with the relation:

$$D = d \cdot \sqrt{n} \tag{1}$$

where: D = collectors diameters; d = individual pipe diameter (suction or discharge); n = number of pumps (here 2).
Suction collector: Individual pipe: 1¼" ≈ 32 mm
$D = 32 \cdot \sqrt{2} = 32 \cdot 1.41 = 45.12 \text{ mm}$. **Recommended diameter**: DN50 mm (2")
It is chosen the following superior diameter: **DN50 mm (2")**, for reducing suction losses and cavitation risk.
Discharge collector: Individual pipe: 1" ≈ 25 mm
$D = 25 \cdot \sqrt{2} = 25 \cdot 1.41 = 35.25 \text{ mm}$. Recommended diameter: DN 40 or even **DN 50 mm (2")**.

3.2.2 Calculation of the flow rate variation

3.2.2.1 For the pump with variable rotational speed:

In order to assure the cooling of the engine with variable rotational speed drive, minimum rotational speed value of the adjustable pump must be 1/5 from the nominal rotational speed of the electric engine. At this value the engine torque decreases at 70% from the maximum torque.

$$n_{min} = \frac{1}{5} n_n = \frac{1}{5} \cdot 2850 = 570 \, rpm$$

The variation interval of the rotational speed of the adjustable pump is: *570...2850 rpm*
At centrifugal pump, load characteristic curve [3] can be exemplified with the following equation:

$$H(Q) = H_0 - kQ^2 \tag{2}$$

where: H_0 is pumping height at zero flow (closing height) and k is a coefficient that cumulates the geometry effect of the pump rotor and the losses effect of the intern load.
The graph of this equation of the second order is a quadratic curve, that represents the set of points from the plane of coordinates *(Q,H)*.
We use the pairs of values *(Q,H)* from the table 1, at n_0=2850 rpm we have two points on the characteristic curve of the pump: *Point 1:* $(Q_1=1.5 \text{ m}^3/h, H_1=70 \text{ m})$; *Point 2:* $(Q_2=12 \text{ m}^3/h, H_2= 39 \text{ m})$
Replacing these values in equation (2) we obtain: $70= H_0-k \, 1.5^2$, respectively $39= H_0-k \, 12^2$

Results: $H_0=70.942$ *m*; *k=0.218695*; $Q_0=17.95$ m^3/h

Observations:

- In technical data sheet of electric pump, the value of the height (table 1) is *72 m*, very close to the value resulted from the calculation ($H_0=70.942$ *m*).
- $Q_{0,2850}=17.95$ m^3/h is the theoretic flow of the pump at the zero pumping height.

The laws of similitude [3], applied to centrifugal pumps for two similar functionality regimes (the same pump at different rotational speed), mention that the flow varies direct proportional with rotational speed, the pumping height varies direct proportional with rotational speed at square, and the absorbed power by the pump varies direct proportional with rotational speed at cubic power:

$$\frac{Q}{Q_0}=\frac{n}{n_0};\ \frac{H}{H_0}=\left(\frac{n}{n_0}\right)^2;\ \frac{P}{P_0}=\left(\frac{n}{n_0}\right)^3 \tag{3}$$

When n_0 represents reference rotational speed and *n* represents the new rotational speed, maximum and minimum reports of the speed variation are:

$$s_{min}=\frac{570}{2850}=0.2;\quad s_{max}=1$$

Complete theoretical interval of the flow variation, corresponding to variation of the pumping height at H_0 at zero, is:

at $n_{max}=2850$ *rpm, Q* belongs to the interval *[0,17.95]* m^3/h;

at $n_{min}=570$ *rpm, Q* belongs to the interval *[0,0.2 x 17.95] = [0, 3.59]* m^3/h.

So, totally, adjusting rotational speed (from variable frequency drive) *570-2850 rpm* the theoretical maximum flow of the adjustable pump varies between *0-17.95* m^3/h.

At rotational speed decreasing, at the same load ends, the two points change as follows:

For ***H=70*** (point 1): *Q(n)=sx1.5*. At *n=570* results: *Q=0.2x1.5=0.30* m^3/h. At *n*=2850 results *Q=1.5* m^3/h.

For ***H=39*** (point 2): *Q(n)=sx12*. At *n=570* results: *Q=0.2x12=2.40* m^3/h. At *n*=2850 results *Q=12* m^3/h.

If are compared the same two points (*H=70 m* and *H=39 m*) at different speeds, the numeric results are:

At H=*70*, Q belongs to the interval *[0.30, 1.50]* m^3/h;

At H=*39*, Q belongs to the interval *[2.40, 12.00]* m^3/h.

Table 2: The pump flows at different rotational speeds for two heights (falls) (H = 70 m and H = 39 m)

n (rot/min)	$s = n/n_0$	Q at H = 70m (m^3/h)	Q at H = 39m (m^3/h)
570	0.200	0.2 x 1.5 = 0.30	0.2 x 12 = 2.40
855	0.300	0.3 x 1.5 = 0.45	0.3 x 12 = 3.60
1140	0.400	0.4 x 1.5 = 0.60	0.4 x 12 = 4.80
1425	0.500	0.5 x 1.5 = 0.75	0.5 x 12 = 6.00
1710	0.600	0.6 x 1.5 = 0.90	0.6 x 12 = 7.20
1995	0.700	0.7 x 1.5 = 1.05	0.7 x 12 = 8.40
2280	0.800	0.8 x 1.5 = 1.20	0.8 x 12 = 9.60
2565	0.900	0.9 x 1.5 = 1.35	0.9 x 12 = 10.80
2850	1.000	1.0 x 1.5 = 1.50	1.0 x 12 = 12.00

In figure 2 are presented load characteristic curves H=f(Q) of the adjustable centrifugal pump, at different rotational speeds, between the interval *570 rpm* and *2850 rpm*.

At starting: $H_0(Q)=70.492 - 0.218695\ Q^2$ (for $n_0 = 2850$ *rpm*).

Adjusting of rotational speed: with step 10% from n_0.

For ***H=70 m*** results: $70=70.492 - 0.218695\ Q^2$. So, ***Q=1.499*** m^3/h;

For ***H=39 m*** results: $39=70.492 - 0.218695\ Q^2$. So, ***Q=11.999*** m^3/h.

Observations:

- In fig. 2 is observed how to move load characteristic curve of the pump when the rotational speed increase from the minimum value of *570 rpm*, to the maximum value of 2850 *rpm*. At minimum rotational speed $H_{max}=3m$ and $Q_{max}=3.5$ m^3/h, and maximum rotational speed

$H_{max}=71m$ and $Q_{max}=18\ m^3/h$. The graph was drawn for variable *s*, with step of *0.1*, in the interval *[0.2,1.0]*;

- The load characteristic curve of rotational speed *n=2850 rpm* passes through the point 1, of coordinates $(Q_1=1.5\ m^3/h,\ H_1=70\ m)$ and the point 2, of coordinates $(Q_2=12\ m^3/h,\ H_2=39\ m)$.

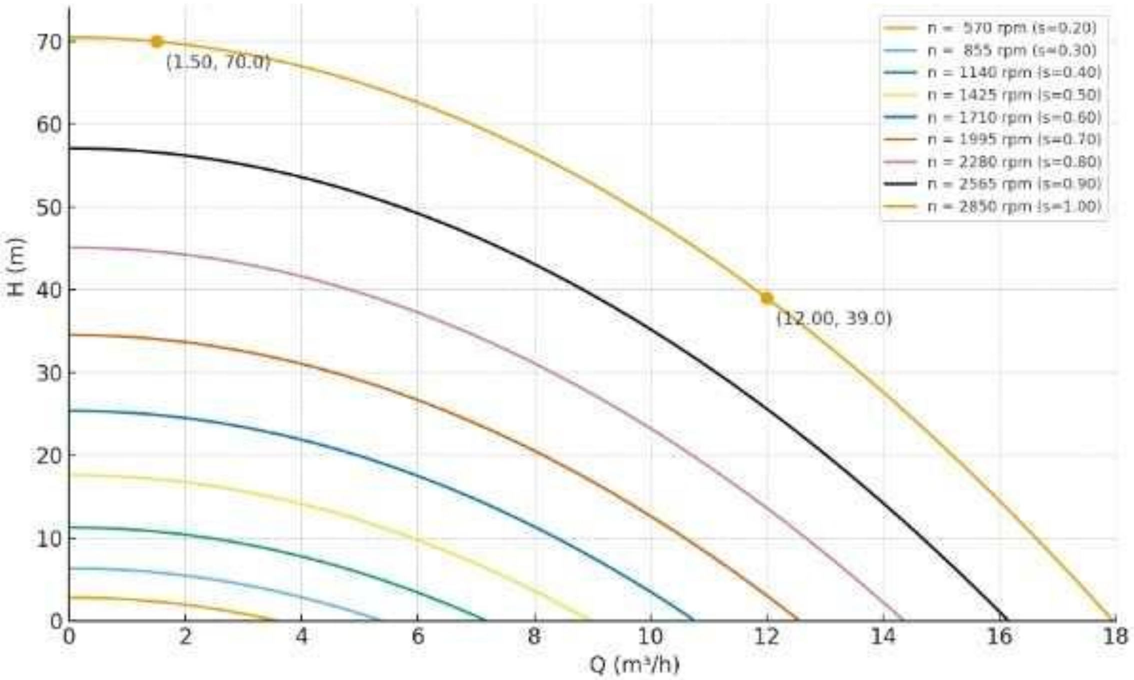


Fig. 2. Load characteristic curve H = f(Q); adjustable pump at different rotational speeds

3.2.2.2 For the pumping group made from two identical pumps coupled in parallel:

The pumping group is made from two identical pumps, coupled in parallel, one variable with drive rotational speed between *570...2850 rpm* and other fix, driven at the nominal rotational speed of *2850 rpm*.

At coupling in parallel [5], at the same pumping height H the flow rate of the two pumps Q_{total} is added:

$$Q_{total}(H,n) = Q_{fix}(H) + Q_{var}(H,n) \tag{4}$$

If the fix pump functions at the rotational speed n_0 and the variable pump at the rotational speed $n = s\ n_0$, according to the laws of similitude, at the same pumping height *H*, the following linear relation between flow rates results:

$$Q_{total}(H,n) = (1+s)\ Q_{ref}(H) \tag{5}$$

Where $Q_{ref}(H)$ is the the flow rate of a pump at the rotational speed n_0 and the pumping height (fall) *H*.

Reference data, at $n_0 = 2850$ *rpm* are:

at *H=70 m*, each pump has $Q_{ref}(70)=1.5\ m^3/h$;

at *H=39 m*, each pump has $Q_{ref}(70)=1.5\ m^3/h$;

at *H=0 m*, for a single pump $Q_{0,\ 2850}=17.95\ m^3/h$.

Rotational speed factor *s* varies between $s_{min}=570/2850=0.2$ and $s_{max}=1$.

Total flow rate of the pumping group, at the two falls when *s* varies between *0.2* and *1* is:

For *H = 70 m:*

$Q_{total} = (1 + s)1.5$, respectively for *s=0.2*, results $\boldsymbol{Q_{total} = 1.8m^3/h}$, for s=1.0, results $\boldsymbol{Q_{total} = 3m^3/h}$;

For *H = 39 m:*

$Q_{total} = (1 + s)12.0$, respectively for *s=0.2*, results $\boldsymbol{Q_{total} = 14.4m^3/h}$, for s=1.0, results $\boldsymbol{Q_{total} = 24.0m^3/h}$.

Variation interval of the flow rate at zero load (*H=0*) is:

$Q_{0,\ total}(s) = Q_{0,\ 2850}(1+s)$, so for s from the interval *[0.2,1]*, $Q_{0,\ total}$ belongs to the interval *[1.2 x 17.95, 2 x 17.95]* = ***[21.54, 35.90]***
In table 3 are presented the key value of the pumping group at three pumping heights:

Table 3: Key values of the flow rate of the pumping group

Size Q_{total} at certain H	For s=0.2 (n=570rpm)	For s=1 (n=2850rpm)
Q_{total} la $H = 70\ m$ (m³/h)	1.80	3.00
Q_{total} la $H = 39\ m$ (m³/h)	14.40	24.00
Q_{total} la $H = 0$ (m³/h)	21.54	35.90

Generation of load characteristic curve of the pumping group made from fix pump driven by the rotational speed n_0*=2850 rpm* and the adjustable *pump (570...2850 rpm).*
Load curve of a single pump driven at rotational speed n_0 is:

$$H_0(Q) = 70.492 - 0.218695\ Q^2 \qquad \text{(Q in m}^3\text{/h).}$$

General equation of a load curve of an adjustable pump is:

$$H(Q,s) = s^2 H_0 - aQ^2 \tag{6}$$

So, adjustable pump curve, with factor $s=n/n_0$ is: $H_0(Q) = s^2\ 70.492 - 0.218695\ Q^2$
For a certain fall H the flow rate of a pump $Q = \sqrt{(A-H)/B}$ if $(A-H)/B > 0$
In conclusion the total flow rate of the two pumps coupled in parallel is:

$$Q_{tot}(H,s) = Q_{fix}(H) + Q_{var}(H,s) \tag{7}$$

For the moment doesn't exist technical data about hydraulic network in which the pumps function (valve **12** of the load simulation from fig.1). From this reason, were overlapped three representative network load curves of form $H_{sist}(Q) = H_s + kQ^2$, for: *easy system* (H_s*=5m, k=0.03); medium system* (H_s*=10m, k=0.07); heavy system* (H_s*=15m, k=0.15).* The graph was drawn for variable *s*, with the step of *0.05*, in interval *[0.2,1.0]*.
At the intersection of the network curve with the load curves exist *functioning points* of group. *There* were marked on a graph few functioning points, of coordinates *(Q,H)*, respectively: ***s=1.0***, three functioning points *(27.01, 28.2); (22.02, 44.0); (16.46, 55,7);* ***s=0.8***, three functioning points *(24.69, 23.3); (19.16, 35.7); (13.77, 43,6);* ***s=0.7***, one functioning point: *(12.27, 37,6); s= 0.55*, one functioning point: *(14.47, 24.7);* ***s=0.50***, one functioning point *(18,83, 15,7);* ***s=0.40***, one functioning point *(16.23, 12.9).*

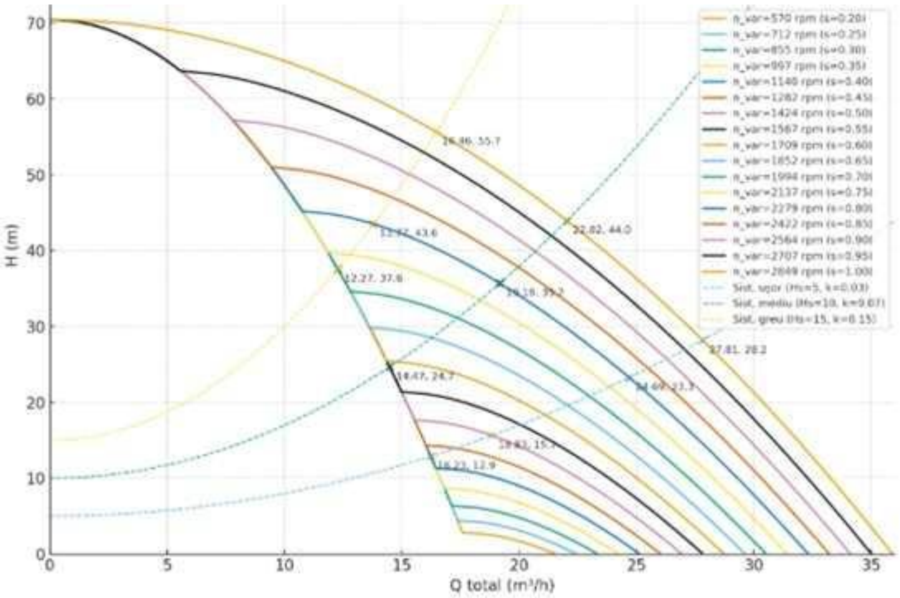


Fig. 3. Load characteristic curves H = f(Q), at different rotational speeds, overlapped over three network curve (fix pump coupled in parallel with adjustable pump)

Few values of the flow rate of the pumping group, extracting from the figure 3:
For H=0 we have $Q_{tot}=21.545\ m^3/h$, at $s=0.20$ and $Q_{tot}=35.895\ m^3/h$, at $s=1.00$;
For H=39 m we have $Q_{tot}=14.400\ m^3/h$, at $s=0.20$ and $Q_{tot}=24.00\ m^3/h$, at $s=1.00$;
For H=70 m we have: $Q_{tot}=1.800\ m^3/h$, at $s=0.20$ and $Q_{tot}=3.000\ m^3/h$, at $s=1.00$.

Table 4: Total flows rates for different rotational speeds for three falls (H=0, H = 39 m, H = 70 m)

n_{var} (rpm)	s	Q_{tot} at H=0 (m^3/h)	Q_{tot} at H=39 (m^3/h)	Q_{tot} at H=70 (m^3/h)
570	0.200	21.54	12.00	1.50
670	0.235	22.17	12.00	1.50
770	0.270	22.80	12.00	1.50
870	0.305	23.43	12.00	1.50
970	0.340	24.06	12.00	1.50
1070	0.375	24.69	12.00	1.50
1170	0.411	25.32	12.00	1.50
1270	0.446	25.95	12.00	1.50
1370	0.481	26.58	12.00	1.50
1470	0.516	27.21	12.00	1.50
1570	0.551	27.84	12.00	1.50
1670	0.586	28.47	12.00	1.50
1770	0.621	29.10	12.00	1.50
1870	0.656	29.73	12.00	1.50
1970	0.691	30.36	12.00	1.50
2070	0.726	30.99	12.00	1.50
2170	0.761	31.62	14.92	1.50
2270	0.797	32.25	17.11	1.50
2370	0.832	32.88	18.68	1.50
2470	0.867	33.51	19.99	1.50
2570	0.902	34.14	21.15	1.50
2670	0.937	34.77	22.23	1.50
2770	0.972	35.40	23.23	1.50

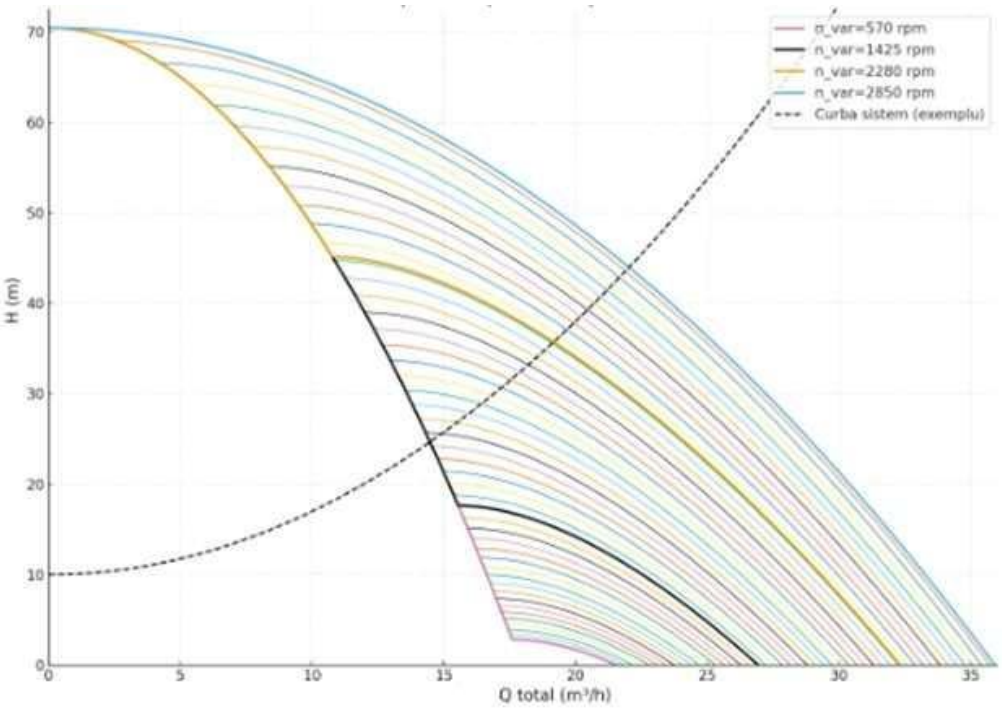
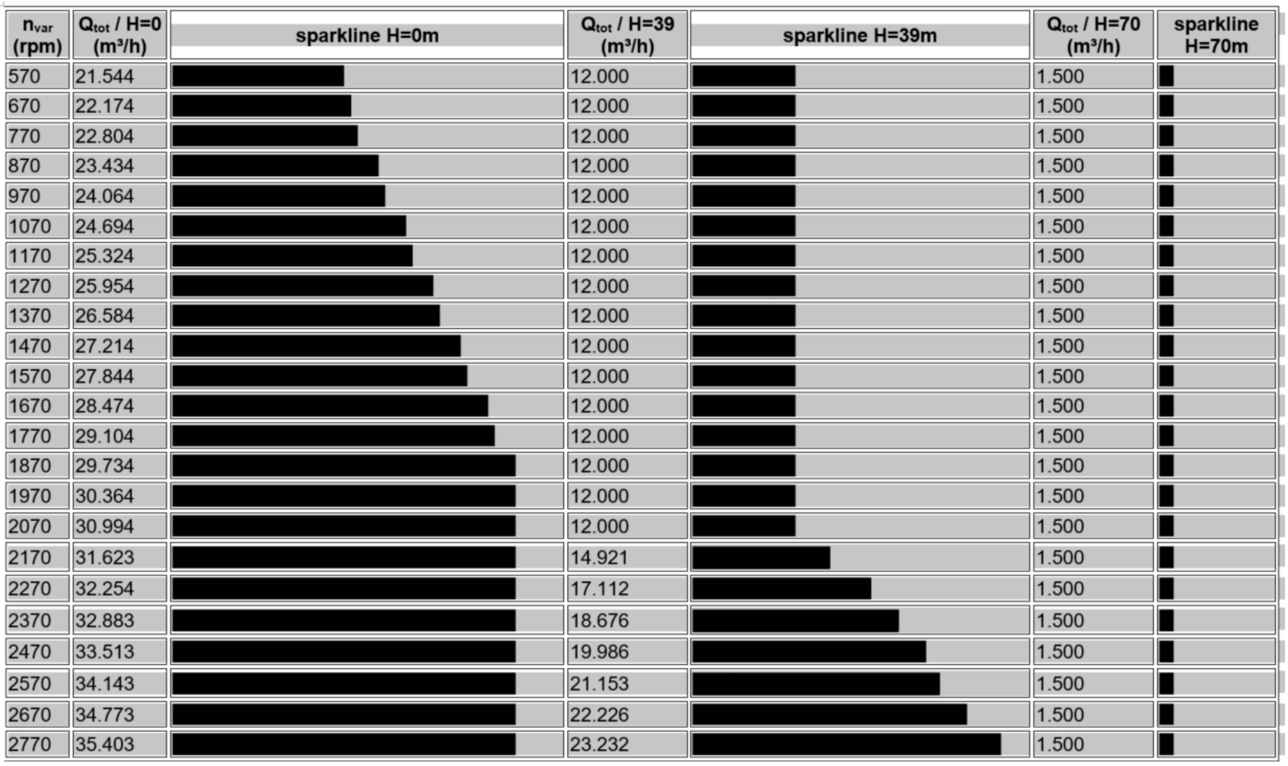


Fig. 4. Load characteristic curve H = f(Q), at different rotational speeds over a network curve (fix pump, coupled in parallel with an adjustable pump)

If rotational speed variation of the adjustable pump is made with more fine steps, for instance *100 rpm*, results the values of the flow rate from the table 4, and characteristic curves of the pumping group from the figure 4, which are overlapped only of one single network curve. In fig. 4 were mentioned load curves at four rotational speeds n_{var}, respectively: *570, 1425, 2280, 2850 rpm*.
The values tendency from table 4 is presented in linear graph from figure 5.



n_{var} (rpm)	Q_{tot} / H=0 (m³/h)	sparkline H=0m	Q_{tot} / H=39 (m³/h)	sparkline H=39m	Q_{tot} / H=70 (m³/h)	sparkline H=70m
570	21.544		12.000		1.500	
670	22.174		12.000		1.500	
770	22.804		12.000		1.500	
870	23.434		12.000		1.500	
970	24.064		12.000		1.500	
1070	24.694		12.000		1.500	
1170	25.324		12.000		1.500	
1270	25.954		12.000		1.500	
1370	26.584		12.000		1.500	
1470	27.214		12.000		1.500	
1570	27.844		12.000		1.500	
1670	28.474		12.000		1.500	
1770	29.104		12.000		1.500	
1870	29.734		12.000		1.500	
1970	30.364		12.000		1.500	
2070	30.994		12.000		1.500	
2170	31.623		14.921		1.500	
2270	32.254		17.112		1.500	
2370	32.883		18.676		1.500	
2470	33.513		19.986		1.500	
2570	34.143		21.153		1.500	
2670	34.773		22.226		1.500	
2770	35.403		23.232		1.500	

Fig. 5. Sparkline graphical representation of values tendency from table 4
Sparkline's Scale: **H=0**, sparkline is scaled at maximum flow rate observed for H=0 (**35.403 m³/h**); **H=39 m**, sparkline is scaled at maximum flow rate observed for H=39 (**23.232 m³/h**); **H=70 m**, sparkline is almost constant (**1.50 m³/h**) for majority steps.

4. Conclusions

- For *H=0 m*, the total flow rate increases almost continuously with a variable rotational speed of the pump, between *21.5 m³/h (n=570 rpm)* until at *35,4 m³/h (n=2770 rpm);*
- For *H=39 m,* the flow rate increases almost constantly *at 12 m³/h* until at *2070 rpm* (only the fix pump covers this value). Over *2170 rpm*, the variable pump stars to contribute at the total flow rate, that reaches the value at *23.2 m³/h*;
- For *H=70m,* the flow rate is constant, at the value of *1,5 m³/h,* regardless of the value of the variable pump. Practically, the fix pump determines the maximum flow rate at this height of pumping;
- Variation intervals of the pumping group are:
at *H=0 m*, *21.5...35.4 m³/h*;
at *H=39 m*, *12...23.2 m³/h* (plateau until at *2070 rpm*, then increases);
at *H=70 m*, 1.5 m³/h (without variation);
- The adjustment of the variable pump rotational speed brings considerable flexibility in functioning domains with small and medium falls (*H=0...39 m*), but is inefficient for load close to the maximum pressure (*H=70 m*);
- On the shown stand can be simulated different characteristic curves of irrigation installation (by varying the opening of the load valve, driven by servomotor) and these determine: load characteristics curves of the pumping group (formed by a fix pump and a variable pump);

functioning points in which pumping group works stably, at maximum yield, for constant different values of the pumping height (situated at the intersection of the two types of characteristic curves). The pumping group pressure, simulated by varying the opening of the servomotor valve in the principle scheme of the stand, represents the working pressure of the pumping group consisting of the fixed pump and the adjustable pump, coupled in parallel. This pressure, in a hypothetical plot of irrigation, served by the pumping group, consists of:

- the sum of the linear and local pressure losses on the pump discharge circuit, from the discharge collector of pumping group, to the hydrant in the plot farthest from the it;
- the pressure necessary to supply water to the hydrant, positioned at the highest height relative to the discharge collector of the group;
- working pressure at which the most disadvantaged hydrant (the farthest and the highest situated from the discharge collector source) must operate.

For example, if the pumping group supplies a hydrant, located at 200 m away from the discharge collector of the group, the sum of the local pressure losses, on a horizontal supply circuit is 1 bar, and the working pressure of the hydrant is 1 bar, the opening of the stand's servomotor valve is adjusted at a value corresponding to a pressure of 4 bar.

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