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MECHANICAL-HYDRAULIC CONTROL MECHANISM FOR DIFFERENTIAL PISTON INJECTION DEVICES

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Abstract: *In the development of the injection device of the primary solutions used for underground fertilization of agricultural crops, which is the object of project 5 within the complex project “Innovative technologies for irrigations of agricultural crops in arid, semi-arid and dry sub-humid climate”, contract no. 27 PCCDI / 2018- PN III, we started from the D3 Green Line dosing device produced by Dosatron - France. Compared to the D3 Green Line device, in which the direction of movement of the drive piston - piston injection pump with simple effect mobile assembly is achieved with the help of a spring tilting mechanism, an innovative solution of mechanical-hydraulic mechanism with spring and piloted valves was designed and implemented in the device developed within the project. The differential drive piston dosing device and the piston injection pump have major advantages compared to the volumetric dosing devices with membranes used in agriculture: the volume of the injected fertilizer solution is strictly proportional to the volume of water entering the unit, regardless of the variations of flow or pressure that may occur in the main pipe; the water used as a drive fluid mixes with the primary solution inside the device, forming the fertilizing solution; it is introduced into the pipeline of the localized irrigation plant and diluted to an optimum concentration, which eliminates the risk of crop over-fertilization, thus contributing to the protection of plants, consumer and environment health.*

Keywords*: Fertigation, injection device, differential piston*

1. Introduction

The sandy soils of Romania occupy 460 thousand hectares, most of which, 208 thousand ha, are located in a true "Bermuda Triangle", with the peak in the southern border of Craiova and base - on the Danube, in the counties Dolj, Olt and Mehedinți [1]..The sandy soils belong to the group of soils with a more pronounced manifestation of the extreme phenomena (atmospheric drought, pedological and agricultural drought, strong burns and a major deficit in precipitations with uneven distribution during the vegetation period of the plants). All these lead in the vast majority of the years of culture to the drastic diminution of the production on the plants of the big culture, of the orchards of the trees and the vines, often going to compromise the crops in question.
The thermal resources, the strong insulation and the irrigation during the drought periods can favorably influence the agricultural crops on the sandy soils. The possibility of using these poorly fertile soils and the early production (7-10 days in advance of other areas) are some arguments for the development of horticulture in these areas in particular.
On the sandy soils, the stone fruit species (peach tree, apricot tree, cherry tree, sour cherry tree) give the best results.
The methods used to reduce the action of stressors for agricultural crops on the sands are:
• Selection of species with short vegetation period (potato, melons);
• Selection of tolerant and drought resistant varieties based on physiological criteria (rate of transpiration, rate of photosynthesis, water forms);
• Management of agrotechnical factors in order to increase the efficiency of plant metabolism (irrigation, fertilization, disease control and pests).
Irrigation and fertilization of crops on sandy soils, in arid climatic conditions is achieved by the multi-phase application with reduced norms of water and fertilizer, in order to avoid their

evaporation and percolation under the root layer, taking into account the high temperatures during the vegetation period and the reduced sand soil capacity of water retaining.
Under these conditions, fertigation is the most efficient method of water and fertilizer administration [2].

2. Material and method

The differential piston injection device, fig. 1, [3] can be located both on the main hydraulic circuit of the irrigation system (full flow), and on a circuit parallel to it (by-pass), and it uses irrigation water as a drive fluid. The device consists of two functional subassemblies: the subassembly acting as linear hydraulic motor and the subassembly acting as single-effect piston volumetric pump.
The motor subassembly consists of two bodies, assembled together by threading and sealed with O-ring.
The body 1 consists of two concentric tubes: in the inner tube, of cylindrical form, the part of diameter d1 of the motor piston is displaced, while the outer liner is provided with the inlet connections for the water used as a motor fluid and the discharge connections for the fertilizing solution (formed by mixing the primary solution with water).
The body 2 is of cylindrical shape inside; inside of it the motor piston part of diameter d_2 ($d_1 < d_2$) moves.

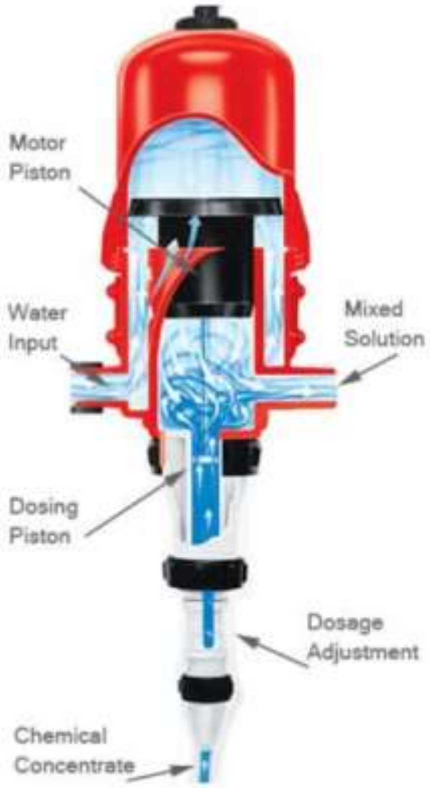

Fig. 1. Schematic presentation of the injection device with DOSATRON differential piston

Inside the motor assembly, fig. 2, three work chambers are made: chamber A, delimited by the outer surface of the inner cylindrical tube of the body 1, the inner surface of the liner of the body 1, the inner surface of the body 2 and the lower part of the motor piston, in the area of diameter d_2; chamber B, delimited by the upper part of the motor piston in the area of diameter d_2 and the inside of the body 2; chamber C, delimited by the lower part of the motor piston in the zone of diameter d_1 and the inside of the cylindrical tube of the body 1.
The pressurized water supply connection pipe communicates with chamber A, and the fertilizer solution discharge connection pipe - with chamber C.

The subassembly of the volumetric pump with piston is connected by threading to the lower part of the body 1.
During operation, the motor piston and the volumetric pump piston (which form the mobile assembly of the injection device) move in the same direction, as they are joined by a rod.
The water acts on the motor piston of the injection device. The change of direction of movement of the mobile assembly is controlled by the tilting mechanism, located in the motor piston, which by actuating two blocks of valves on the cone allows the access of water acting as drive fluid below or above the piston.
Pressurized water enters through the inlet connection in chamber A. If the valve train 2.4 in the motor piston 2.1 is moved up (see the left side of fig. 2) then the valves 2.2 close the connection between the chambers A and B and the valves 2.3 open the connection between the chambers B and C. Between A and B the liquid forms a pressure difference that acts on the annular surface of the motor piston and produces an upward movement of it. The fluid from chamber B is evacuated through the open valve 2.3 in chamber C where it is mixed with the primary solution arrived from the dosing area and then directed to the discharge. If the valve train is moved down (see right side of fig. 2), the valves between the chambers A and B are opened and the valves between the chambers B and C are closed. The pressure in the chambers A and B is uniformed; the pressurized fluid passes into the chamber B, and acts on the cylindrical surface of the drive piston between B and C and moves the piston down.

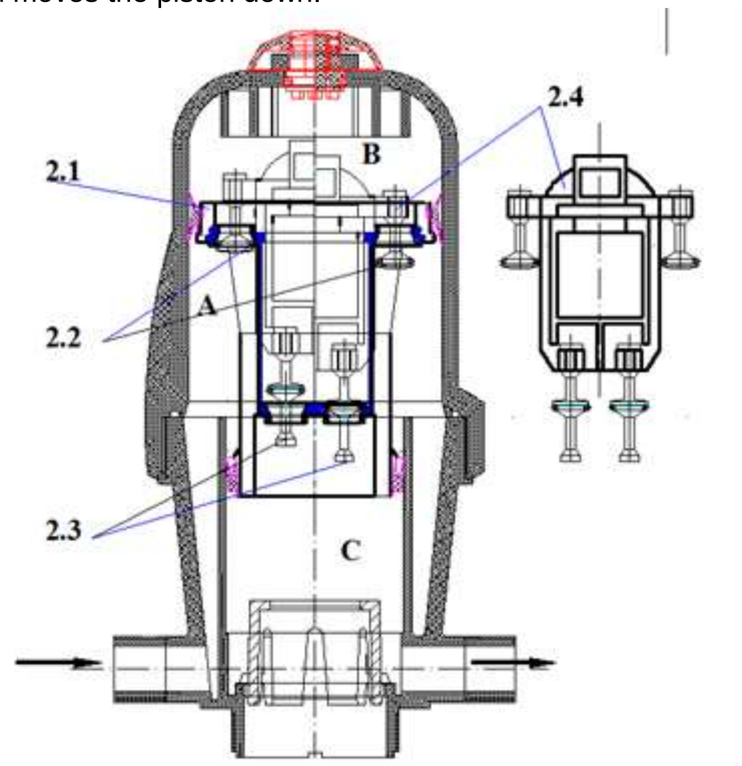

Fig. 2. Cross section through the motor assembly of the injection device with DOSATRON differential piston
Section to the left of the axis of symmetry-ascending stroke of the drive piston; Section to the right of the axis of symmetry-descending stroke of the drive piston

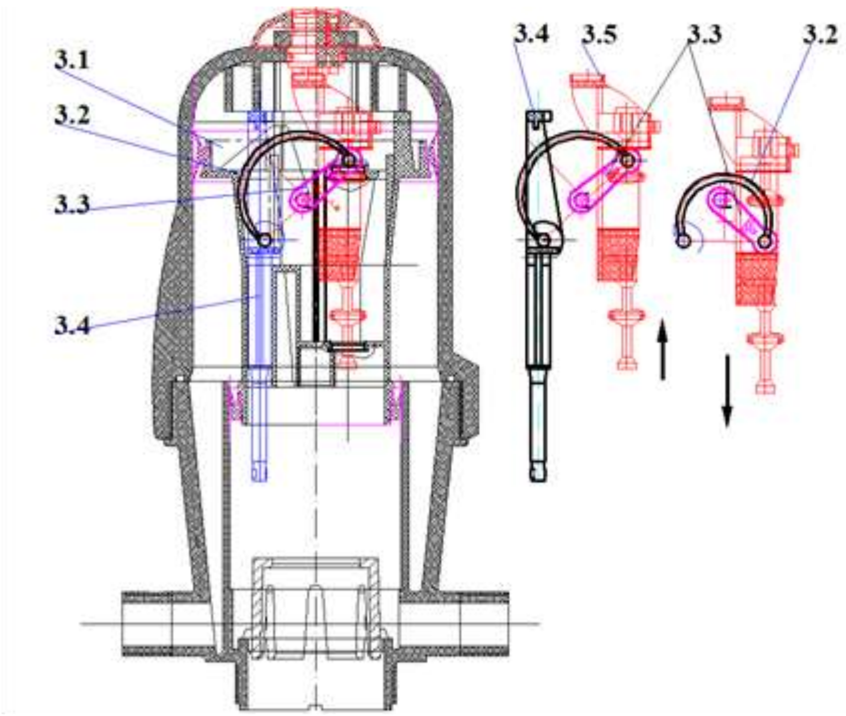

Fig. 3. Tilting mechanism of the of the injection device with DOSATRON differential piston

The tilting mechanism, located in the motor piston 3.1, controls the valve train; it has the following structure:
- the probe 3.4, which moves in a fit in the motor piston 3.1;
- a plastic spring 3.2 hinged to the probe, forming the probe-spring joint;
- the other end of the spring is hinged to the oscillating rod 3.3, forming the spring-rod joint;
- the oscillating rod 3.3 is connected to the motor piston 3.1 through the rod-piston joint.

Approaching the ends of the stroke, the probe 3.4, by leaning on the housing, changes the position of the spring-probe joint, with respect to the motor piston 3.1, respectively the positions of the rod-piston and spring-rod joints.
Under the action of spring 3.2, the joint assembly is unbalanced, tilting the mechanism up or down, depending on the displacement of the probe relative to the motor piston. By tilting, the mechanism hits the valve train 3.5, which it pushes up or down, closing or opening the connections between the chambers A, B, C.
The change of the displacement direction of the motor piston is made mechanically, the stroke being fixed (preset, in terms of construction, by the geometrical dimensions of the tilting mechanism).

3. Results and discussions

In the constructive version of the drive piston made by INOE 2000-IHP, the valves on the cone, actuated by the tilting mechanism with spring were replaced by hydraulic piloted valves [4], which establish the connections between the chambers A and B, respectively between the chambers B and C.

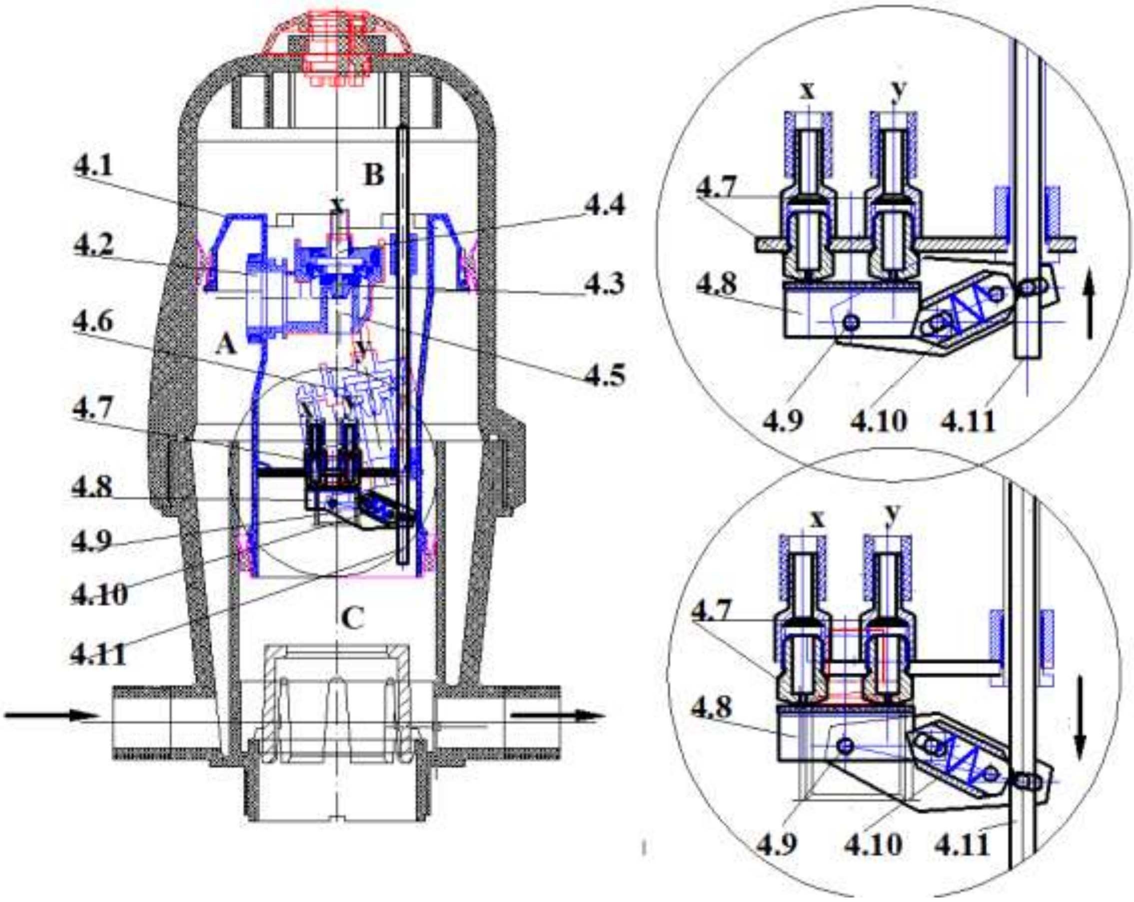

Fig. 4. Constructive variant of the motor piston made by INOE 2000-IHP

The piloting is done with the help of a piece 4.8 (on the surface of which a rubber tape is applied by gluing), which by tilting around the shaft 4.9 alternately closes one of the two nozzles 4.7, thus piloting the two hydraulic valves through the connections x-x or y-y.
The hydraulic valve consists of the tubular part 4.5, which in the inactive state is closed by membrane 4.3. The membrane, the surface of which is larger than the surface of the tubular part, is mounted in the valve housing.
The water enters behind the membrane through the port 4.2 and closes the pilot chamber 4.4, acting on the active surface formed from the sum of the cross-sections of the tubular part 4.5 and annular section delimited by the outer diameters of the membrane and the tubular part.
In the membrane there are ports (nozzles) that establish the communication between the inlet port 4.2 and the pilot chamber. If the tilting device 4.8 closes the nozzle 4.7 related to the valve, then the pilot chamber 4.4 is closed, the pressurized water from the entrance entering the pilot chamber through the ports in the membrane; under the action of the water, the membrane presses on the tubular part 4.5 and closes the path between the chambers A and B. The pressure in the pilot chamber acts on the whole surface and creates a force greater than the same pressure exerted only on the annular surface.
By tilting the pilot device at the stroke end (through the probe 4.11, which drives the compression spring-guide assembly 4.10 and tilts the part 4.8 on the nozzles 4.7), the pilot chambers of the two valves are opened alternately; by opening the ports of the pilot chambers the pressure in the chambers decreases, the membranes are raised and the communication between the chambers A and B (for the upper valve) and B and C (for the lower valve) is established.
The dosing piston, pos. 1.5- fig. 4, joined with the drive piston through a rod, is provided with a sleeve-type translation seal, which in the upward stroke sits on the lower seat, ensures perfect

sealing with the dosing cylinder and creates the depression required to lift the disc valve with the spring from the seat, thus allowing access of the primary solution under the piston and causing driving of the primary solution volume from above, existing inside the piston from the previous stroke, in the drive fluid-primary solution mixing chamber (motor piston cylinder).

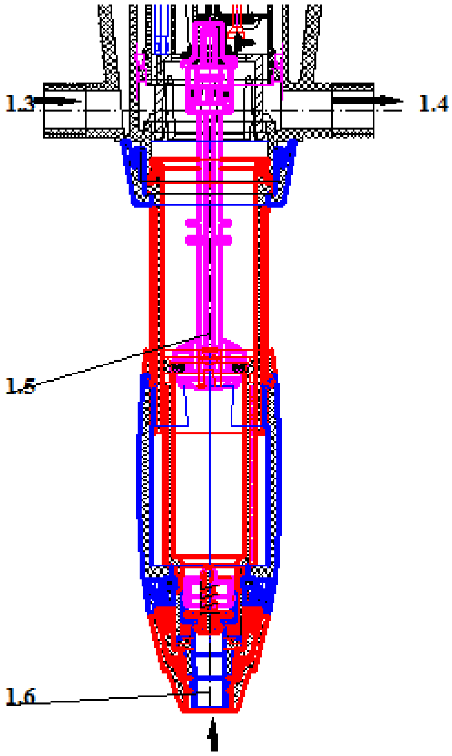

Fig. 5. Injection device dosing pump

In the downward stroke, the sealing piston of the dosing piston is placed on the upper seat of the piston and allows the access of the volume of primary solution already introduced in the dosing cylinder above it during the previous stroke, through the longitudinal slots on the external generators; by continuously varying the volume of the mixing chamber, in order to reduce it, the fertilizing solution is injected by the pump discharge connection into the irrigation system. During this time the inlet valve of the primary solution is placed on the seat, under the action of the spring.
The laboratory tests, carried out on the test stand for devices and equipment that use water as working fluid, from the infrastructure of the Environmental Protection laboratory of INOE 2000-IHP, have demonstrated the functionality of the injection device in the version designed and developed under the component project 5 “Innovative fertigation technology in fruit and vine plantations specific to arid and dry sub-humid climate” within the complex project “Innovative technologies for irrigation of agricultural crops in arid, semi-arid and dry sub-humid climate – SMARTIRRIG”, contract no. 27PCCDI / 2018.
To highlight the way in which the pressure varies, during a functioning cycle, in the connection points of the device to the localized irrigation system, its installation on a circuit parallel to the main circuit of the system (bye-pass) was done. The pressure sensors, located at the mentioned points, were connected to a programmable logic controller which, based on dedicated software, allowed real-time monitoring of the investigated parameters and data acquisition.
Fig. 6 shows the stand for conducting tests on the device in laboratory conditions, and fig. 7 depicts a screen instance of the computer with which data acquisition was made.

Fig. 6. Testing the injection device with differential piston under laboratory conditions

Fig. 7. Acquisition of data regarding the variation of pressures in the connection points of the device to the main pipe of the stand (the equivalent of the main pipe of the localized irrigation system)

The tests were performed with both constructive variants of the drive piston. Fig. 8 shows variation of pressures at the connection points for the drive piston with valve train on mechanically operated cone, belonging to the device DOSATRON D3 Green Line 3 m^3/h, and fig. 9 – the same, for the drive piston with hydraulic piloted valves.

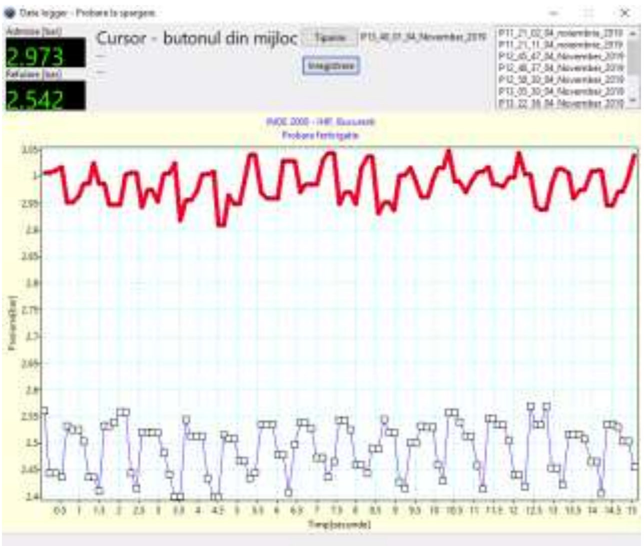

Fig. 8. Variation of pressures at the connection points for the drive piston with valve train on mechanically operated cone

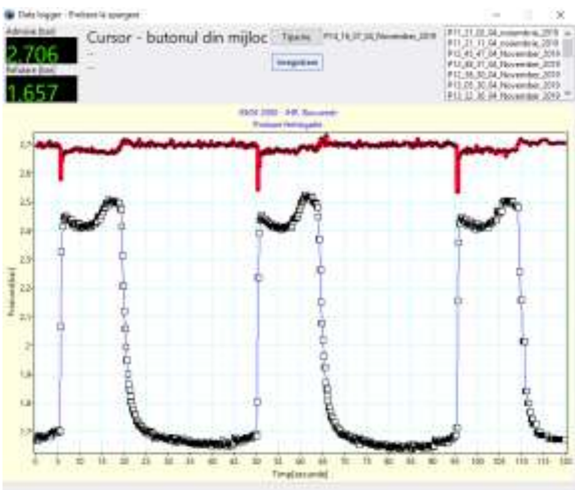

Fig. 9. Variation of pressures at the connection points for the drive piston with hydraulic piloted valves

4. Conclusions

1. The laboratory tests have demonstrated the functionality of the primary solution injection device developed under the component project 5 “Innovative fertigation technology in fruit and vine plantations specific to arid and dry sub-humid climate” within the complex project “Innovative technologies for irrigation of agricultural crops in arid, semi-arid and dry sub-humid climate – SMARTIRRIG”, contract no. 27PCCDI / 2018.
2. For similar working pressures (around 3 bar upon the device inlet port), the primary solution flow rate injected by the Dosatron device is 3000 l/h, for a switching frequency (change of the direction of movement of the drive piston - dosing piston assembly) of 10 s, while the primary solution flow rate injected by the experimental model (EM) developed by INOE 2000 under the mentioned project is 600 l/h, for a switching frequency of 45 s; primary solution flow injected by the EM meets the technical parameters of the fertigation process conducted for horticultural crops on sandy soils, which requires fragmented administration of liquid fertilizers; at a phase fertilization, an amount of 150-200 l /ha of primary solution is usually administered.
The switching frequency of the drive piston can be adjusted through the diameter of the nozzles 4.7, fig. 4.
3. The switching frequency of the motor piston can be adjusted by the diameter of the nozzles 4.7, fig. 4.
4. The tilting mechanism of the motor piston injection device with piloted valves requires an actuating force 5 times smaller than that of the mechanically actuated motor piston device.
5. The injection device realized within the project responds to the requirements of the fertilization of agricultural crops on sandy soils under arid climatic conditions, having the possibility of administering fertilizer norms in accordance with the agricultural technologies practiced in this category of soils.

Acknowledgements

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