

Hose manipulation with jet forces

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Abstract: The innovation was drafted in search of a technically more advanced and safer strategy of firefighting. The resulting solution has a strong interdisciplinary character as it requires and utilizes the knowledge of mechanical engineering, electrical engineering as well as computer science.

In all of the existing patents which exploit the thrust forces of jets of liquid, the jets were always positioned only at the end of the supply hose. This fact severely limits the range of access of the known solutions as the gravity force of the supply hose and the contained liquid is too large and inappropriately oriented to allow any serious practical usage. The distribution of the jets of liquid and their thrust forces along the supply hose is the natural solution to this problem and actually the essence of this innovation. By adding the ability of changing and controlling the thrust and direction of every single jet of liquid, we get a device which can lift off and allows us to control its stable hovering and movement.

Keywords: Patent, jet force, water, hose, device, hovering, movement

1 Introduction

To achieve stable hovering of the hose the thrust forces of the jets of liquid need to be of the same size and have the opposite direction in relation to the resultants of the gravitational and potential wind forces that the hose is exposed to. Any change in the size or direction of the forces will spoil the balance and result in the movement of the hose.

At the beginning of this contribution, the device construction and the utilized principles are described. The relevant physical background is included in order to explain its influence on the feasibility and usefulness. The presentation of the current prototype is followed by a section related to the control of the device. Theoretical usage possibilities are briefly explained at the end of the contribution.

2 Device description and utilized principles

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2.1 Device description

The basic building element of the system (*Figure 1*) is an active unit for splitting the flow of liquid which comprises an inner sleeve (pos. 1) and an outer housing (pos. 2) [1, 2]. The sealed rotation (pos. 5) of the housing around the inner sleeve is controlled by a small electric motor (pos. 10) via a gear transmission (pos. 11). An electronically controlled valve (pos. 8 and pos. 13) and a nozzle (pos. 9) are fluidly attached to the rotatable outer housing. The valve is regulating

the flow of the liquid which is exiting the housing and flowing towards the nozzle. In general, the jet of liquid is perpendicular to the axis of the unit, but this angle can be changed to a certain extent by rotating the nozzle in the plane going through the imaginary axis of the unit.

Such unit construction allows arbitrary control of the flow and the direction of the jet of liquid and at the same time, the necessary control of the size and direction of the corresponding thrust force.

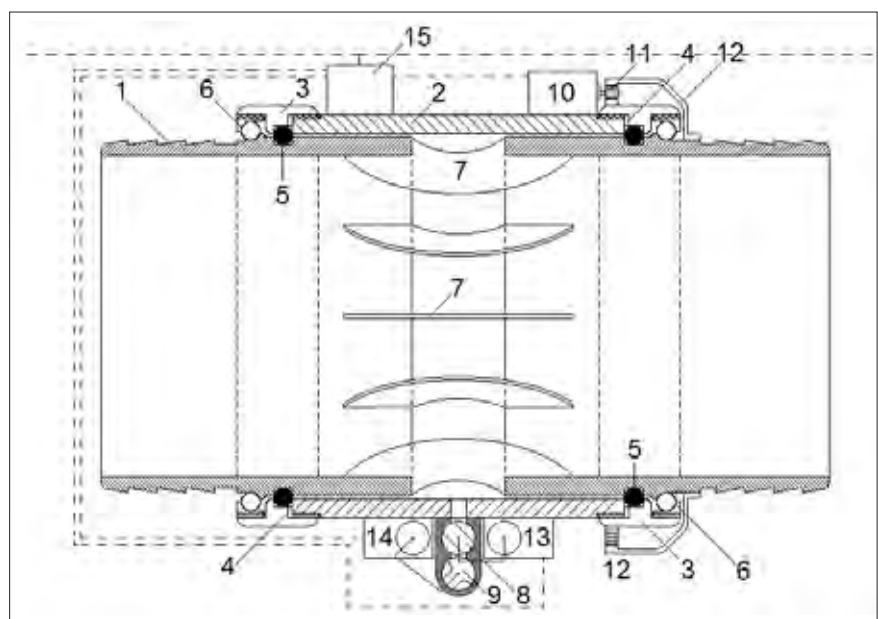


Figure 1. Basic unit construction [1, 2]

When multiple aforementioned units are serially interconnected and appropriately spaced with segments of a flexible high pressure hose and one end is connected to a source of pressurized liquid, we get a device that can overcome its own weight, and allows us to control its stable hovering and movement.

2.2 Relevant physical background

The size of the jet thrust force is regulated by changing the flow of the liquid through the valve and the nozzle. The maximal thrust force has to be greater than the total weight of the device segment that it has to carry. This includes the weight of the unit, the adjacent segment of the hose and the weight of the contained liquid.

The thrust force (F) of a jet of liquid (Equation 1) depends on the square of its exit speed (v), the exit surface area (A) and the specific density (ρ) of the selected liquid (ρ of water = 1000 kg/m^3) [3].

$$F = \rho \cdot A \cdot v^2 \quad (1)$$

The exiting speed (v) of the jet (Equation 2) depends on the difference (Δp) between the pressure of the liquid in the hose and the external air pressure and also on the specific density (ρ) of the selected liquid [3, 4].

$$v = c_v \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}} \quad (2)$$

The factor c_v ($0 \leq c_v < 1$) decreases the exiting speed of the liquid due to the pressure drop in the exit installation. This pressure drop mostly depends on the valve position and it is used for regulating the thrust force.

The results of theoretical calculations pertaining to a single segment of the device show that sufficient thrust force can be achieved with the existing pumps for liquids.

Calculations derived from formulas (1) and (2) show that the volume-

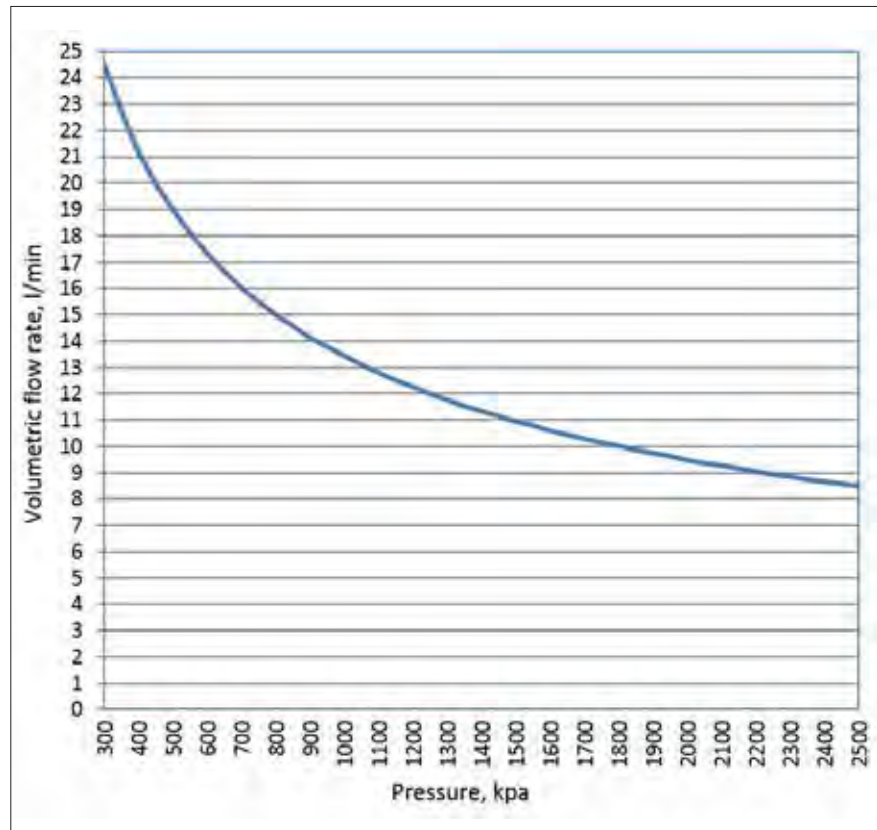


Figure 2. Volumetric flow rate of water with 10 N jet force at different pressures

tric flow rate necessary to achieve a certain thrust force decreases considerably with the increase of the pressure, Δp (Chart 1). At higher pressures, the exiting speed of the liquid is higher and the nozzle diameter for achieving the same thrust force is smaller.

This means that the pressure of the liquid source has an important influence on the feasibility of building a useful hose manipulation device. A higher pressure and smaller volumetric flow rates of jets distributed along the length of the hose at the same time mean lower speeds of the liquid streaming through the hose and a smaller pressure drop along its length.

The results of this calculation point to the conclusion that the theoretical length of the device mostly depends on the power of the pump which needs to provide a sufficient volumetric flow rate of the liquid at a sufficiently high pressure and on the capability of the device to withstand such high pressure.

3 Prototype design

The inner sleeve, the housing, the valve and the nozzle are all machined from aluminium, while the base for attaching the servo motors and the toothed wheel are 3D printed with ABS plastic. Figure 3 shows a three-dimensional design of the device prototype, and Figure 4 its realisation.



Figure 3. Design of the prototype

■ 4 Three-dimensional calculations of flow through device

After the three-dimensional modelling of the patented device [1, 2], it is necessary to optimize its design of channels from the inlet to the outlet nozzle with a straight jet. A numerical model, an appropriate mesh and parameters have been set. Then the water streamline velocity profile and the pressure drop of flow through the device have been calculated.

■ 4.1 Velocity of flow-streamlines

The flow velocity profile is mostly dependent on the geometry of the flow path, therefore calculations and later optimisations are needed. *Figure 5* shows streamlines and *Figure 6* the velocity profile of water flowing through the prototype device to the nozzle at the end with a flow of 50 l/min. It is obvious that the maximum velocity, 47 m/s, is achieved at the elbow near the end of the flowing path. This velocity is lower when the nozzle is positioned perpendicularly to the main hose.

■ 4.2 Pressure drop through device

The pressure drop due to the viscous friction of water flow through the device is important with regard to the characteristics of the water system pump. Such pumps are often hydrodynamic pumps, so they cannot reach pressures as high as hydrostatic pumps in power-control hydraulics. *Figure 7* shows the pressure drop profile of the water flow through the device. The maximum pressure drop is 1.17 MPa at a flow of 50 l/min.

■ 5 Controlling the device

Every unit of the device is equipped with its own microprocessor controller and the necessary sensors for determining the position and movement of the unit. This electronic circuit is generating signals for the direct control of servo motors. It can be programmed and parameterized for autonomous operation.



Figure 4. The first prototype of the basic unit

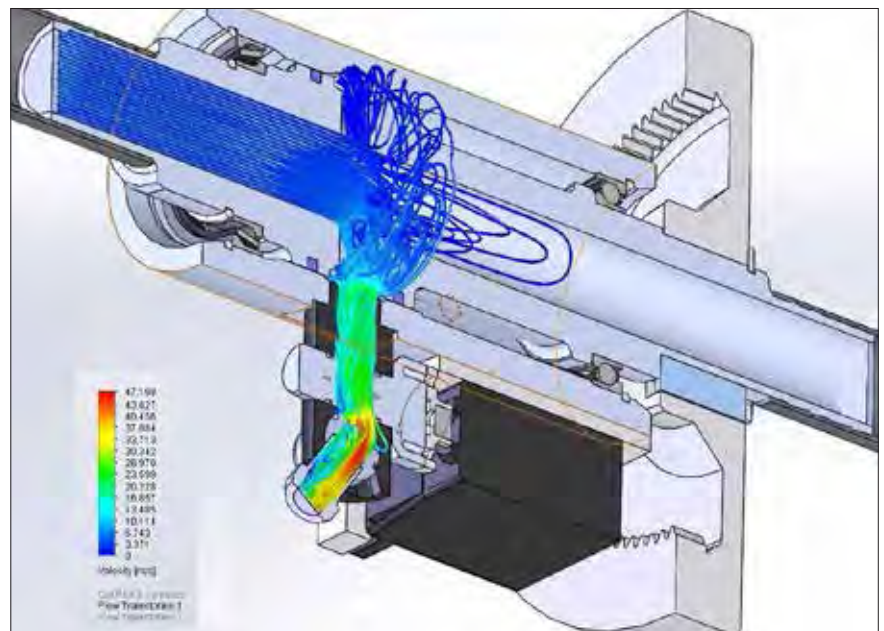


Figure 5. Streamlines of water through jet

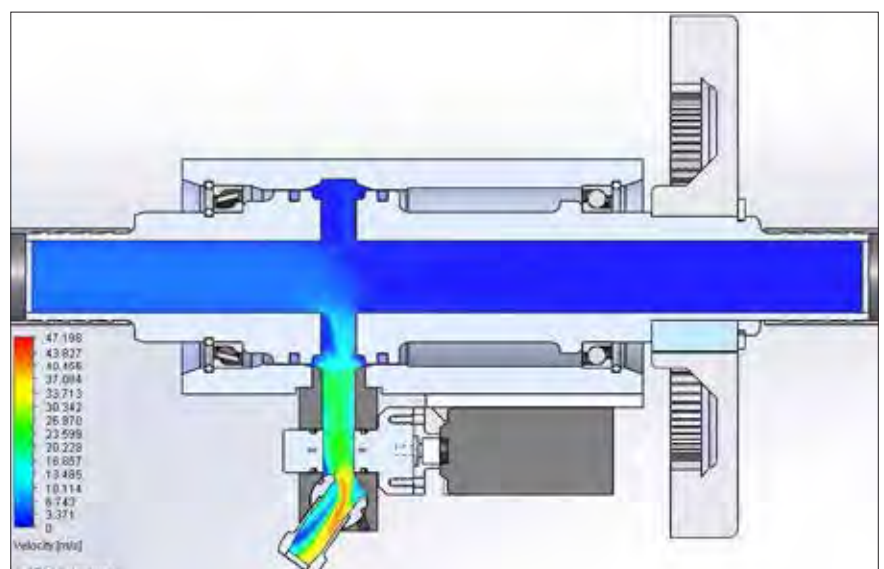


Figure 6. Calculated flow velocity profile of water through device

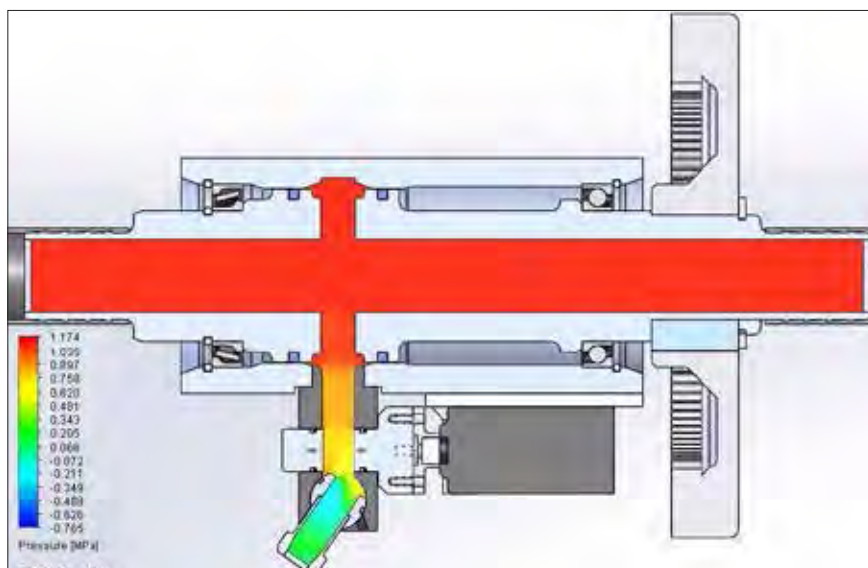


Figure 7. Calculated pressure drop through device

It is also capable of mixing input command signals with the pre-programmed response signals which are based on the sensor inputs.

For more complex movement and controlled reshaping of the device, the operation of the controllers has to be coordinated by a computer. A two-way communication with every single controller has to be established and constantly maintained for that purpose. The cable which is powering the device can also be used for establishing the necessary communication network.

On the basis of the data received from the controllers, the computer is able to determine the position, the shape and any movement of the device. This information is used for the calculation and issuing of corrective commands to corresponding controllers.

The selection of appropriate sensors depends on the size and specific usage of the device. Electronic gyroscopes and accelerometers for all three spatial axes are most probable and almost mandatory. Additional sensors may include pressure sensors, magnetometer based compasses, GPS receivers, ultrasonic distance sensors, and the sensors for the measurement of wind and temperature.

For a precise remote control of the device, optical and/or thermal ca-

meras could be mounted at the end of the device. For guidance through narrow openings and inside buildings, stereoscopic cameras would be very useful for providing a 3D FPV (First-Person View) to the operator.

■ 6 Possibilities of usage

■ 6.1 Firefighting

The search for a new, safer way of firefighting was the main motivation and the source of the idea. For the firefighting purpose, the device would need to be thermally insulated from the external high temperatures. Luckily, the water flowing through the hose is effectively cooling the device from the inside. A portion of the water could even be sacrificed and used for cooling the external surface of the thermal insulation.

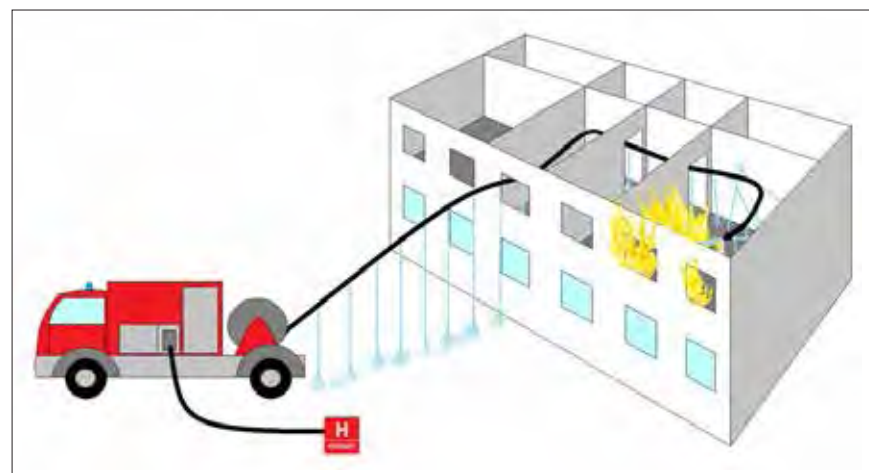


Figure 8. Urban firefighting

For urban firefighting usage (Figure 8), the device would most probably be equipped at its end with at least one (possibly thermal) camera and a larger remotely directed jet of water with a compensated thrust force (with opposite jets). Installation and usage of the sprinklers for generating the fog of small water droplets is possible practically anywhere on the device.

To avoid unnecessary loss of water for reaching fire on higher floors, the reel where the device is wound could also be mounted on top of an extendable pole or a ladder.

A large scale device for wildfire fighting would require a very powerful pump and a practically endless source of water in the vicinity of the pump (river, lake or sea). Vessels floating on the water seem to be very well suited for that purpose due to the abundance of water and the presence of a powerful driving engine which can also drive the pump. The curtain of jets of water is expected to be very efficient for extinguishing and preventing the spread of wildfire.

■ 6.2 Cleaning and maintenance

Often, reservoirs have very small openings. This fact usually makes the cleaning and maintenance of the interior a difficult task. Most likely, there are corners that are almost impossible to reach.

With a smaller scale version of the aforementioned device, every corner of a reservoir interior could be reached. Powerful jets of liquid can mechanically remove and flush the accumulated sediments.

In the case of a hydraulic reservoir maintenance, jets of hydraulic oil could be used instead of water. The time and effort needed to remove water from the reservoir could be eliminated in this way.

Similarly, the device could be used for the removal of moss and rotten leaves from the roofs of buildings.

■ 6.3 Some other usage possibilities

- Transporting the rescue rope to a drowning person on heavy seas, or on thin ice
- Transporting the towing rope between ships or landing rope on heavy seas
- As a mobile device for the irrigation of farmland
- For snow production and covering the ski slopes (with some technical adjustments)

- Quick laying of a temporary water supply installation
- For decorative purposes as an attractive dynamic fountain
- Underwater manipulation and rescue operations (capsized vessels)

■ 7 Conclusion

The article presents the basic idea for hose manipulation with jets of liquid, for which a Slovenian patent has been granted and an international patent application has also been filed. The main idea of the invention is to lift, hover and to control the movement of the device connected to a water firefighting hose.

The basic theoretical calculations of the thrust force in connection to the flow rate and pressure drop were introduced. For 10 N of thrust force at water flow rate of 13 l/min, a pressure supply of 1 MPa is needed. The maximum calculated flow velocity through the device is 47 m/s and the maximum calculated pressure drop is 1.1 MPa at 50 l/min.

The presented patented device can be used for different applications, such as firefighting, cleaning, rescue aims, etc. The prototype of the presented device was constructed and the first measurements will be done in the near future.

References

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Manipulacija cevi s silami pretočnih curkov

Razširjeni povzetek

V prispevku je predstavljena inovacija, namenjena predvsem izboljšanju varnosti pri gašenju požarov. Patentirana rešitev je interdisciplinarna, saj povezuje strojniška, elektro- in računalniška znanja. Vsi obstoječi patenti, ki uporabljajo silo curka, to vedno izkoriščajo samo s konca cevi. To pa zaradi lastne teže cevi in vode v njem omejuje njeno uporabnost. Razporeditev sil curkov vzdolž cevi je logična rešitev problema, kar predstavlja inovacija v tem prispevku [1, 2]. Ko dodamo vsakemu posamičnemu curku vzdolž cevi še možnost nastavitve smeri v dveh oseh in velikosti pretoka, dobimo napravo, ki omogoča lebdenje in kontrolirano gibanje cevi po prostoru.

Slika 1 prikazuje zgradbo osnovne enote patentirane naprave [1, 2], ki jo sestavljajo jedro, ohišje, vrtljiva šoba, trije majhni elektromotorji in drugo. Na *sliki 2* je prikazana izračunana odvisnost pretoka vode od tlačne razlike skozi šobo za zagotavljanje konstantne sile curka 10 N. *Slika 3* prikazuje tridimenzionalno zasnovano, *slika 4* pa izdelan prototip osnovne enote naprave. Pred izdelavo prototipa so bili narejeni numerični izračuni. *Slika 5* prikazuje tokovnice, *slika 6* pa izračunan hitrostni profil vode pri pretakanju skozi patentirano napravo za krmiljenje curka vode. *Slika 7* prikazuje numerično izračunano tlačno razliko pri pretakanju vode skozi napravo od vstopa v jedro do iztoka skozi šobo, *slika 8* pa možnost uporabe naprave pri gašenju v poslopju brez prisotnega gasilca.

Mehanski del prototipa naprave je bil izdelan, sedaj sledijo še razvoj krmilno-nadzornega dela, testiranja in morebitne izboljšave.

Ključne besede: patent, sila curka, voda, cev, naprava, lebdenje, premikanje