Aspect about Design of Experiment (DOE) to Study the Impact Forces Produced by Water Jets Used in Sewage Cleaning

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Abstract: *The purpose of this paper is to present the steps necessary to make a design of experiment with application to study the impact forces produced by water jets used to cleaning the sewage system. The functioning of the cleaning sewer is dependent on certain process parameters, which can vary, causing variations of the impact forces. The research method used is that of the full factorial design of experiment. In the first part of the experimental research the Taguchi method shall be used to determine the percentage of influence of parameters involved in the process.*

Keywords: *Design of experiment, impact forces, water jet*

1. Introduction

Throughout history, as the first cities emerged, the issue of managing the rain and waste water consequently occurred. This has proven to be a real challenge. The first evidence of the sewerage systems being used goes back as early as the 4th century BC. As of the 19th century, together with the development of the modern sewerage systems, emerged the issue of cleaning and maintaining them. At first „primitive" methods were used for sewer cleaning, such us: different types of flush sewers, "pills" (round wooden balls pushed downstream by the sewage), bucket on wheels or a disk pulled through the pipe. When a sewer was entirely stopped up, a "sewer rod" was pushed into the obstruction. Early rods used short lengths of pipe or wood, which were assembled together and forced through the obstruction.
As of the middle of the 20th century, simultaneously with a higher reliability of the high pressure pumps, was used high pressure water jet-based equipment for sewer cleaning. Such equipment is also currently being used. Also, have been developed water jet and abrasive water jet cutting machine which are used into a full scale production process [6].
The main components of the equipment used for sewer cleaning are the high pressure pump and the cleaning heads. They generate water jets at the necessary working pressure. There are more types and sizes of cleaning heads based on the purpose of the activity in question (the diameter of the sewer to be cleaned, the type of material deposited, the type of obstruction) and based on the characteristics of the pumps (the provided pressure and water flow).
At the outlet of the cleaning head nozzles water jets under pressure appear, which generate impact forces. By means of these impact forces the cleaning of the sewers takes place.
Phenomena that occur in the cleaning water jets are complex. Adler [1] describes mechanisms occurring at the impact of a jet with a surface. Leach et al [3], Leu et al [4] and Guha et al [2] analysed pressure distribution along centreline of the water jet. A number of papers have studied the influence of nozzle geometry on water jet [5].
In the water jet cleaning process a series of parameters are involved [7]. These parameters can be divided into two major groups, namely: 1) target parameters which shall be defined according to the contact area between the water jet and the surface to be cleaned and 2) process parameters.
The aim of this paper is to present the design of experiment (DOE) to study the impact forces, which are dependent on certain process parameters (these process parameters can be set by the operator of equipment for cleaning and maintenance of sewer systems).

2. Management of experimental research

To carry out an experimental research, it is recommended to follow a series of steps [8]:

1) recognition of and statement of the problem;
2) selection of the response variable;

3) choice of factors (process parameters), levels, and ranges;
4) choice of experimental design;
5) performing the experiment;
6) statistical analysis of the data;
7) conclusions and recommendations.

2.1 Recognition of and statement of the problem

After completing field of bibliography, can be formulated the research question is formulated as follows: study pressure water jets used in cleaning head sewerage systems, in order to produce effects depending on certain parameters involved in the process.

2.2 Selection of the response variable

Given the geometry of cleaning heads, in sewer system we deal with the issue of force (generated by pressure water jets) in two directions:

a) dislocation and release of deposits from the work area by pushing into outlet space (behind the cleaning head) through free water jets (cleaning heads);

b) use of water jet force for training the cleaning head and creating impact force of head in order to fracture, dislocation and breakage deposits (pointed heads, wire rope and chain scrapers, gliding heads).

Given the phenomena occurring under cleaning head sewer system, response parameter studied is the impact forces produced by pressure water jets.

2.3 Choice of factors involved in the process (process parameters)

For cleaning sewer, the parameters involved in the cleaning sewer process were identified in the references [7]. These parameters can be divided into two broad categories:

1) target parameters for deposit removal. This parameters which shall be defined according to the contact area between the water jet and the surface to be cleaned (deposit thickness, cleaning with, mass removal, cleaning rate);

2) process parameters, which can be divided into two groups. The first group refers to hydraulic parameters (work pressure p, volume flow Q, nozzle diameter D). The second group is the performance parameters (stand-off distance x, traverse rate v_t and impact angle α).

Parameters directly involved in determining the impact forces of pressure water jets are the process parameters (figure 1).

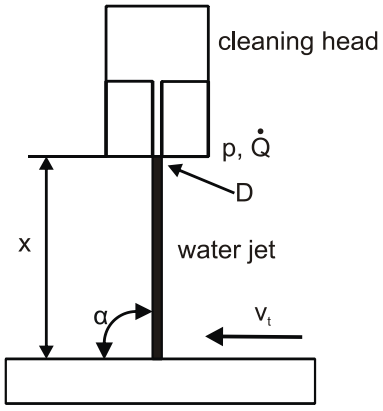


Fig. 1. Process parameters [7]

Because is studying the impact forces generated by the stationary jet it is eliminated the parameter traverse rate v_t. Volume flow Q is an indirectly parameter in the sense that it is determined by the operating pressure p of the jet and the nozzle diameter D.

It is necessary to study four parameters namely: p water pressure at the outlet of the nozzle, D nozzle diameter, x stand-off distance (between the nozzle and impact surface) and the angle α (between water jet and impact surface).

After determining the process parameters it is necessary to choose their values.
Usually, the pressure of water jets are used varies between 120-180 bar pressure to prevent the damage of the sewer pipes. The pressure p is established between 100 and 200 bars with an increment of 20 bars.
It is studying the impact forces in the sewers with a maximum diameter of 400 mm.
The stand-off distance x has been fixed at the values from x=25 mm to x=200 mm, with a step of 25 mm.
For working pressure and diameter sewer previously set, manufacturers recommend cleaning head with nozzle diameter D between 0.3 and 3 mm. As a result nozzle diameter D was set to values of D = 1 mm, 1.5 mm and 2 mm.
For cleaning heads used for sewers with diameters up to 400 mm, the usual value of the impact angle α is 75^0 [9]. If impact angles α decrease below 60^0 it leads to a drop in of the impact forces. Impact angle α was set to values α=60^0, 75^0 and 90^0. Table 1 presents the experimental domain established.

TABLE 1: Experimental domain

Parameter	Abbreviation	Values
Nozzle diameter D[mm]	A	1, 1.5, 2
Pressure p [bar]	B	100, 120,140,160,180,200
Impact angle α [^{0}]	C	60, 75, 90
Stand-off distance x [mm]	D	25, 50, 75, 100, 125, 150, 175, 200

2.4 Choice of experimental design

Type of experiment is used full factorial design. For this four established parameters and there levels, result a number of 3x6x8x3 = 432 experiments.
In order to achieve a statistical analysis of the results, each experiment requires a number of 3 to 7 replications [8]. For statistical analysis of the data, shall be conducted seven measurements for each experiment. It follows a number of measurements required 432x7 = 3024.
At a simple calculation, allocating just 10 minutes for each measurement and given preparation and end times for each day on which measurements are made, result a number of 120 days.
Considering this, in the first part of experimental research Taguchi method shall be used to determine the percentage of influence of parameters involved in the process (screening).
Further, based on the results from Taguchi method will be used full factorial design to study the impact forces.

2.5 Performing the experiments

In order to measure the impact forces, a stand for generating pressure water jets, as well as a device to measure the impact forces were designed and built.
Schematic diagram of the stand to generate a pressure water jet is shown in figure 2.

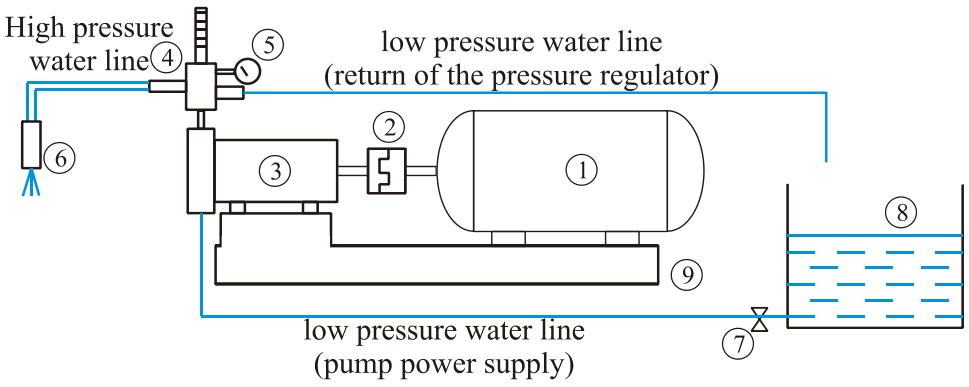


Fig. 2. Schematic diagram of the stand to generate pressure jet

Component parts of stand: (1) electric motor (2) flexible coupling; (3) high pressure pump, 4) pressure regulator, 5) pressure gauge, 6) nozzle, 7) tap water, 8) water tank, 9) chassis.
Water coming out of the high pressure pump (3) goes into the pressure regulator (4). Through it adjusts the pressure and flow of water in the path of the high pressure water. This pressure corresponds to the one at the outlet of nozzle.
In figure 3 is presented the stand to generate pressure jet.

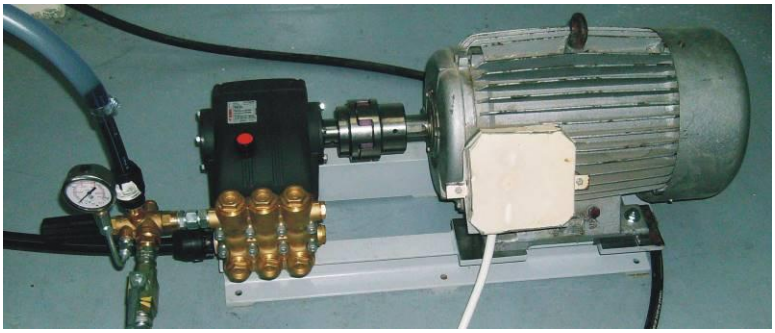
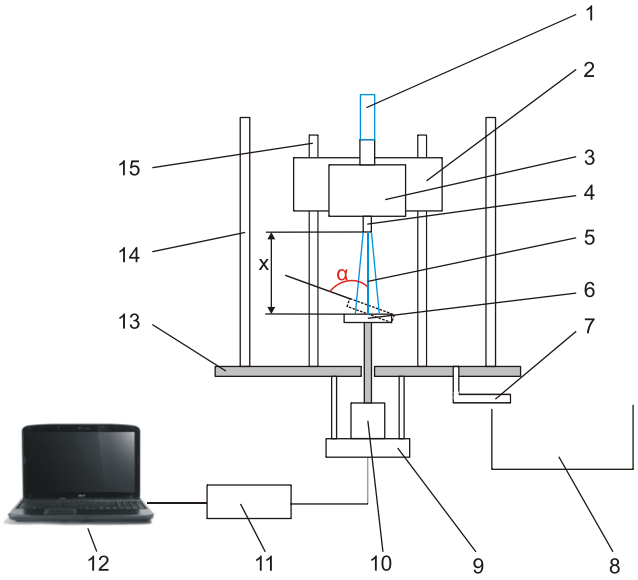


Fig. 3. Stand to generate pressure water jets

In figure 4 is represented the device for the measurement of the impact force of the water jet and a flat and rigid surface.



a) Diagram of the device b) Device realized

Fig. 4. Diagram of the device for the measurement of the impact force of the water jet

The main component parts of the device are:1) high-pressure water hose, 2) support nozzle, 3) nozzle block, 4) nozzle, 5) water jet, 6) flat and rigid target plate, 7) collection path water, 8) scaled container for measurement of the flow of water jet, 9) piezoelectric sensor mounting, 10) piezoelectric sensor, 11) data acquisition Personal Daq/3000, 12) computer for the processing of data; 13) support plate, 14) acrylic tube, 15) rods for adjusting distance x.
From the high pressure water hose (1) the water comes at a certain pressure p desired. A water jet (5) is generated at the outlet of the nozzle (4) that strikes the target plate (6), which it located at a certain distance x in front of the nozzle. The jet (5) generates an impact force at a time when it meets the target plate (6). This force produces axial movement of the target plate. This movement is converted into an electric signal by the piezoelectric sensor (10). Electrical signals are collected by data acquisition Personal Daq/3000 (11), which forwards data to a computer (12) using

DaqView soft processes. Thus, accurate data is obtained.
Using the Taguchi method was determining the percentage of influence of parameters involved in the process (screening). For each of the four parameters set (table 1) will use two values, the smallest and greatest value to determine their influence and interactions between them over the impact forces. In figure 5 are presented the results.

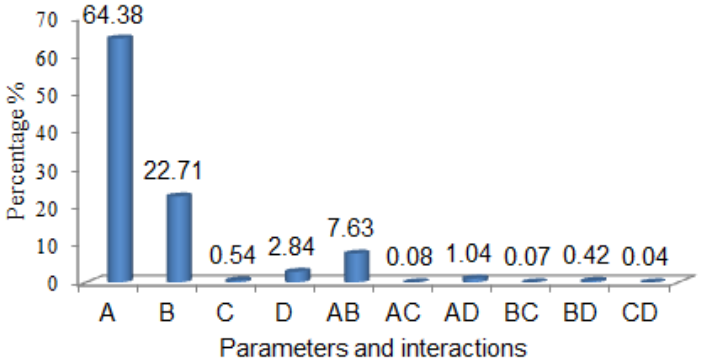


Fig. 5. The percentage of influence of parameters and their interactions

In conclusion, after screening using Taguchi method result, for experimental domain established, only three factors have an important contribution to the impact forces: diameter D, pressure p and angle α.
In the next step, are established the experimental domain to determine the impact forces using the full factorial design (table 2).

TABLE 2: Experimental domain for full factorial design

Parameter	Abbreviation	Values
Nozzle diameter D[mm]	A	1, 1.5, 2
Pressure p [bar]	B	100, 120,140,160,180,200
Impact angle α [^{0}]	C	60, 75, 90
Stand-off distance x [mm]	D	25

For those 3 parameters established (table 2) (after screening using Taguchi method), a number of 3x6x8x1 = 144 experiments results. With seven measurements for each experiment, result a number of 1008 measurements, three times less than was previously established (before carrying out screening using the Taguchi method).

2.6 Statistical analysis of the data
An important role in an experimental research has statistical analysis of the data. Statistical analysis of experimental data obtained certifying that the values are real values of the process studied they are not affected by the system errors or measurement errors.
Statistical analysis of the experimental data consists of:

1) verifying the aleatory character of data. This will be performed using the Young test;
2) To verify the normality of the experimental data distribution will be used Shapiro-Wilk normality test. This test is used for data sets that do not exceed 50 values. In the present case the each data sets have a number of seven values;
3) Identifying data affected by aberrant errors can be accomplished by applying the Romanowski test. This test for identifying data affected by aberrant errors having applies for a number of up to 20 data.

After performing statistical analysis of the data can proceed to modelling the experimental data in order to obtain those mathematical models which best describe the process. With the results of

values of impact forces, for the experimental domain established can be determined an equation who described the impact forces according to the values of process parameters involved.
In figure 6 are presented the chart stages planned in the design of experiment to study the impact forces of water jet.

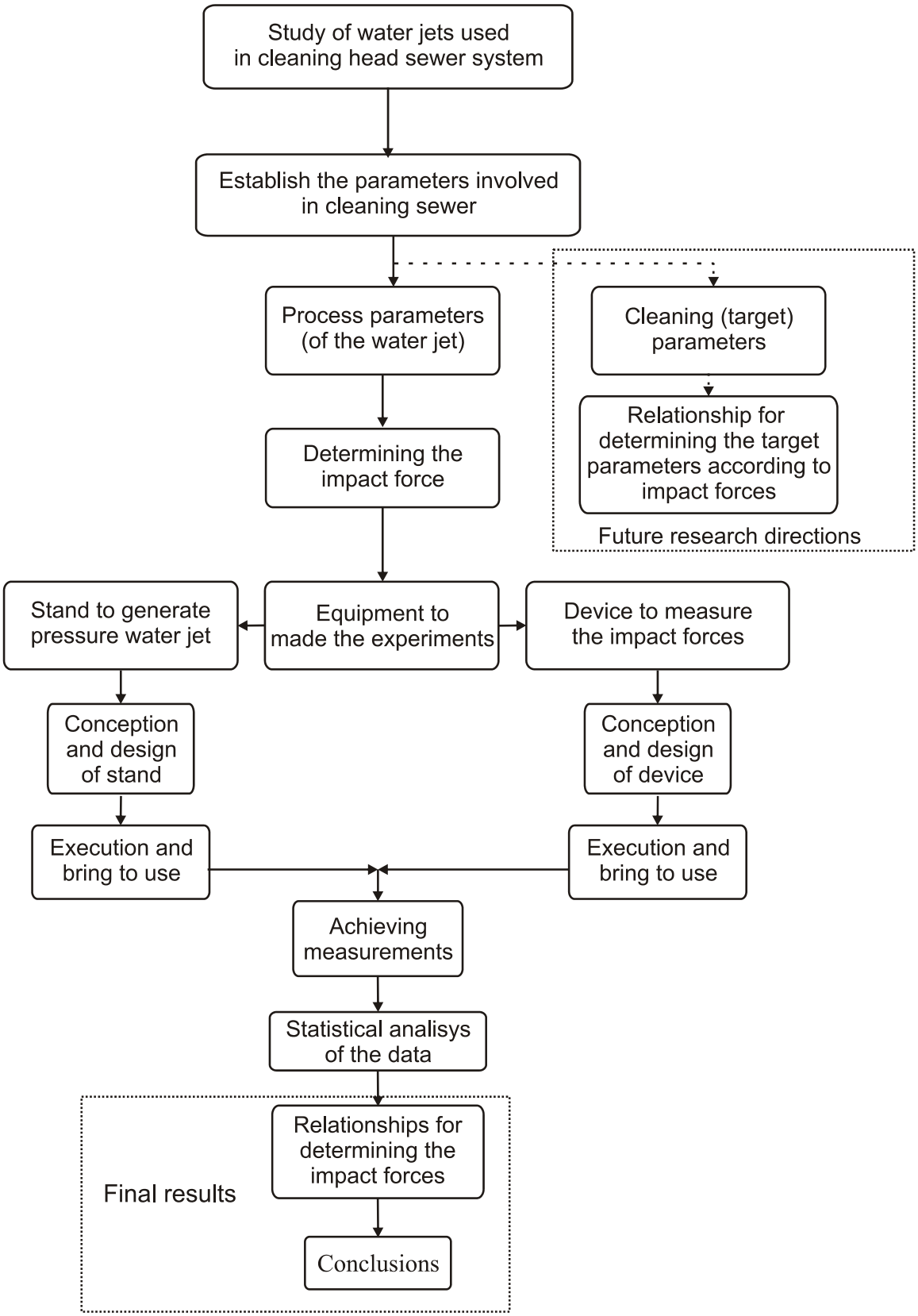


Fig. 6. Chart stages planned in the design of experiment to study the impact forces of water jet.

3. Conclusions

To carry out an experimental research, it is necessary to follow a series of stages, broadly presented in scientific literature. An experimental research aims to obtain results which then can be used to improve the study process.
In the present work was performed the study of impact forces produced by water jets used in cleaning sewer system.
In order to realised the experiments it was necessary to designed and built a stand for generating pressure water jets and a device to measure the impact forces.
The impact forces are depending on certain process parameters. In first stage were determined four process parameters: p water pressure at the outlet of the nozzle, D nozzle diameter, x stand-off distance (between the nozzle and impact surface) and the angle α (between water jet and impact surface). For experimental domain established was necessary a number of 432 experiments. In order to achieve the statistical analysis of experimental data obtained for each experiment was made seven measurements. Result a number of 3024 measurement.
In the first stage of research was used Taguchi method to determine the influence of parameters.
Result that only three parameters have an important contribution to the impact forces: diameter D, pressure p and angle α.
Next, it is used full factorial design to determine the values of impact forces. In this stage it was necessary to make 1008 measurements.
So, using Taguchi method to realise a screening of process, the number of necessary measurements decreased from 3024 to 1008, resulting savings of time and money.
An important part of the design of experiment is represented by statistical analysis of the data obtained.
A direction of further research is to study the cleaning (target) parameters, to determine relationship between these and impact forces.

References

[1] W. F. Adler, "The Mechanics of Liquid Impact", Treatise on Materials Science and Technology, 1979, pp. 127-183;
[2] A., Guha, R. M., Barron, R. Balachandar, "An Experimental and Numerical Study of Water Jet Cleaning Process", Journal of Materials Processing Technology, pp. 610-618, 2011;
[3] S. J., Leach, G. L. Walker, "Some Aspects of Rock cutting by High Speed Water Jets", Philosophical Transactions of the Royal Society of London, Series A, Vol. 260, pp. 295-308, July 1966;
[4] M. C. Leu, P. Meng, E. S. Geskin, L.Tismeneskiy, "Mathematical modelling and experimental verification of stationary waterjet cleaning process", Journal of Manufacturing Science and Engineering, 120(3), 1998, pp. 571-579;
[5] Yayu Liu, Fei Ma, Hui Xie, Yong Li, "Development of Impact Test System for Waterjet Descaling Nozzles with LabVIEW", Web Information Systems and Mining (WISM), 2010 International Conference on , vol.1, no., pp. 3-7, Oct. 23-24, 2010;
[6] I L. Marcu, C. Ciupan, S, "Alternating Flow Hydraulic Generator for Water Jet Cutting Systems", "Hidraulica" (No. 1/2016) Magazine of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics, ISSN 1453 – 7303, pp.61-66;
[7] A. W. Momber, "Hydroblasting and Coating of Stell structures", Oxford: Elsevier Ltd, 2003;
[8] D.C. Montgomery, "Design and analysis of experiments", 8th edition, Wiley, 2013;
[9] ***http://www.enz.com., accessed in November 2016.