

# DESIGN OF THE PUMP CONTROLLER OF THE LOW PRESSURE SEWER NETWORK

JAN RUCKA<sup>1</sup>, ONDREJ ANDRS<sup>2</sup>, JIRI KOVAR<sup>2</sup>,

<sup>1</sup> Brno University of Technology  
Faculty of Civil Engineering  
Institute of Municipal Water Management

<sup>2</sup> Brno University of Technology  
Faculty of Mechanical Engineering  
Department of Production Systems and Virtual Reality  
Czech Republic

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e-mail: [rucka.j@fce.vutbr.cz](mailto:rucka.j@fce.vutbr.cz), [andrs@fme.vutbr.cz](mailto:andrs@fme.vutbr.cz)

The paper deals with the low pressure sewer networks which are used for the systematic drainage of wastewater in locations where it is not technically possible, respectively economically advantageous to build a gravity sewer network. With regard to the size of the urban area, town or drainage site these systems can be very large, involving tens or hundreds of independently working pumps that are connected to the common pipeline system. The right one, or rather the optimal topology design of such a system and performance parameters of its elements is therefore a great challenge. The subsequent operation of the low pressure sewer network system also requires a considerable know-how, particularly with regard to the fact that these are technically complex systems with many components which exhibit a variety of typical operating defects. The removal of these disorders requires a deep understanding of the issues, experience, and availability of adequate industrial solutions. One of the possible failures of the low pressure sewer network is clogging of the pipelines with sediment from wastewater. The following text describes the technical way to prevent the clogging of the pipeline of a low pressure sewer network. This paper presents an intelligent flushing system which is developed within the research project reg. No. TA04010023 at the Faculty of Civil Engineering, Brno University of Technology.

## KEYWORDS

low pressure sewer, operation, design, waste water, clogging, flushing

## 1 INTRODUCTION

The low pressure sewer network (LPSN) compared to conventional gravity sewer network have been used for much less time and therefore there is less experience with their design and operation. The origins of low pressure sewer network are dated back to 1965, when a pressure drainage system was designed for 42 houses in Radcliffe in the USA. In neighbouring Germany, to a greater extent a low pressure sewer network was applied for the first time in 1968 in Hamburg. Numerous low pressure sewer networks were also implemented on the territory of Canada, Hungary (PRESSKAN system) and Slovakia. In the Czech Republic, a low pressure sewer network has been extended since the first half of the 90s [Beranek 1998]. Within the studies of a design, operation and actual behaviour of LPSN the scientific-research project "Smart

pressure sewerage systems" reg. No. TA04010023 is solved at the Institute of Municipal Water Management, Faculty of Civil Engineering, BUT, within which the extensive long-term measurement campaigns and data collection on several real LPSN are carried out which are involved in the project through case studies [Rucka 2015]. The aim of this project is to develop a set of three technical tools which will allow optimizing the operation of low pressure sewer networks. As demonstrated by our past experience, the current level of technique condition does not allow a failure-free operation of LPSN which are equipped with hydrodynamic centrifugal pumps. The systems which are continuously monitored within the above-mentioned project, show some typical malfunctions and failures. Based on current operating experience most often the following failures occur at the existing LPSN – arranged in order of frequency of occurrence starting with the most frequent one: (1) pump failure; (2) control failure; (3) power supply failure; (4) failure of the water level sensor; (5) clogging; (6) pump sump leakage [Miszta-Kruk 2016]. In the case of failures No. 1, 2, 3, 4 and 6, it is a technical malfunction of one element which typically occurs at LPSN, they are expected and can be removed by repairing or replacing of the failing system component. It is, for example, a replacement of a pump, cleaning of water level sensors in the sump, sealing of the joints in the pump sump, etc. These are failures, the occurrence of which can be expected with a certain frequency and operators are able to remove them. The second group of LPSN failures are less frequent but more serious failures of systemic nature which are based on imperfect function of low pressure sewer network as a whole. They are caused by the lack of behaviour knowledge of these systems, the improper design of the sewer network or a lack of technical development level of the used industrial solutions. These are mostly often: (1) a pipeline clogging by solid particles in the waste water; (2) the formation of the underpressure in the pipeline; and (3) the formation of odour in the place of LPSN outfall into gravity sewer network.

The aim of the present project reg. No. TA04010023 is to eliminate all three of the above mentioned types of failures, and the overall optimization of the LPSN operation. The following text, however, describes only a technical way of preventing of the pipeline clogging of low pressure sewer network which is developed within the above mentioned project by the author team of this contribution.

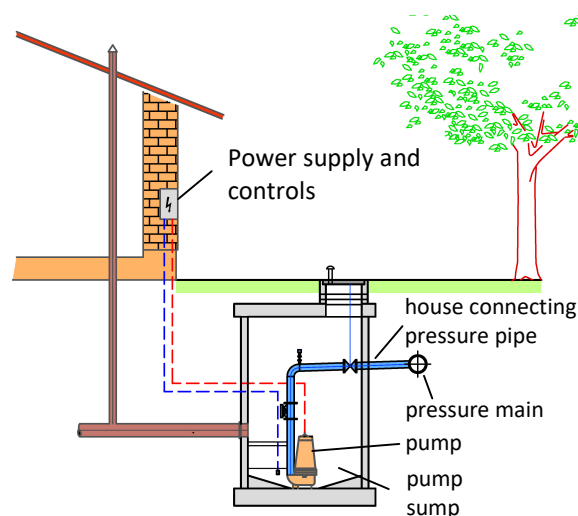


Figure 1. The scheme of the house pump sump of the low pressure sewer network

## 2 CASE STUDY

The low pressure sewer network is a relatively complex technological system which essentially consists of three basic parts. They are: (1) a pump sump, in which the waste water from the connected buildings is accumulated before their further transportation by the system; (2) the pressure generating equipment which is typically a pump or compressor; and (3) pipeline sections which form a branchy pipeline network, see Fig.1.

The wastewater is transported by a pressure pipe away from sources of pressure to the end point of LPSN which may be the outfall of the pipe into the manhole of the gravity sewer network or into the inflow sump in the waste water treatment plant. The technical details of the outfall is usually designed so that there is a possibility of visual control of the quantity and quality of the waste water flowing from LPSN, or to allow also the sampling of water for the analysis, see Fig. 2.

The source of pressure is in most cases submersible pumps, both hydrostatic and hydrodynamic which are fitted with either a grinding device, or not. The transportation of wastewater with compressed air is suggested only in those cases where there is a too long time of a wastewater delay in the pipe and / or in the pipe section the minimum rinsing speed is not reached which continuously prevents the clogging of piping with sediment from the wastewater. The LPSN task, as described in this article, is the systematic draining of municipal sewage wastewater from individual properties to the end point where there is a LPSN outfall. It is a branched pipeline networks whose topological arrangement and size are very diverse and are given by the morphology, shape and size of the drained site. The lengths of these networks are in the range from several hundred meters to tens of kilometres. A typical representative of the municipal low pressure sewer network in the Czech Republic (CR) is LPSN with a total length of 3-6 km, to which from 100 up to 160 pumps are connected. The operation of the pumps is mainly not managed centrally. In the case of wastewater draining from a house which are the most frequent, it is a plastic or concrete pump sump with one submersible pump which is controlled by the autonomous control unit. Starting and stopping the pump is controlled depending on the waste water level in the pump sump regardless of the current conditions in the rest of LPSN. This fact brings about some specifics of the design and operation of the LPSN. The acute technical problem which during the practical operation of LPSN arises and requires an immediate solution is clogging of the pipes by solids from the wastewater.



**Figure 2.** The detail of the outfalling of two separate systems of low pressure sewer network into a common manhole of the gravity sewer network in the wastewater treatment plant



**Figure 3.** Solids from the wastewater form the clogging in the pipeline of the low pressure sewer network and is gradually completely blocked



**Figure 4.** After the unblocking of the clogged pipeline the flushing of the segment is done by a pressure truck; rakings formed into the shape of long cylinders are flushed from the pipeline into the wastewater treatment plant, photo inflow to the wastewater treatment plant

This defect occurs most often in the most remote parts of the network which is equipped with a small number of pumps and the minimum flushing speed is not regularly achieved. Although in such cases, the project designs relatively small pipe dimensions, still often regular flushing of pipes fails. This leads to a gradual accumulation of solids from waste water at specific locations up to a complete clogging of the section, see Fig. 3 and Fig. 4.

The failure usually emerges after a few weeks or even months of operation. A typical manifestation of this defect which can be observed, is the inability of pumps behind the clogged section to pump out water from the pump sump. The clogged section is difficult to find. The pipeline is often placed under paved surface and corrective measures are financially costly.

## 3 OVERVIEW OF THE KNOWN SOLUTIONS

For the above mentioned reasons, a system was developed to prevent the clogging of the LPSN pipes which is based on the controlled flushing of the pipe section which are threatened by this phenomenon. The controlled flushing is achieved by a targeted confluence of pumping by more pumps simultaneously, thereby achieving the required rinsing speed and drain of sediments from the endangered sections further towards the outfall point. The synchronization must be done to



take into account the current state of the system and also from the perspective of the necessary preparation for pumping. As for the controlled synchronized pumping the wastewater in sumps is used, it is necessary to accumulate a sufficient volume of waste water in these pump sumps, wherein the pump will run in advance. From the viewpoint of an immediate operation the synchronization can be solved by communications between the units. For this purpose, a completely new control unit must be necessarily developed which will implement this function into real operation. In existing and licensed control units which are available on the market, this functionality has not been found.

At the beginning of the development work on the new control unit a very detailed patent search was carried out which showed that a beneficiary technical solution is not only unavailable on the market, but so far has not been industrially protected. The file CZ 23662 describes a device for sensing the liquid level in tanks used besides other things for controlling the pumping of low pressure sewer network sumps. The described device solves only local operating conditions and is not capable of communicating with the master system.

AU2012318281 document with the headline "Pressure sewer control system and method" describes a control unit which allows all the usual functions of managing the pump of the low pressure sewer network, including the communication with the controller. The disadvantage of the mentioned known solutions is the lack of operation planning (e.g. using a special computational model) and a possible synchronization of control units' activity of pumping stations which significantly improves the operation of low pressure sewer networks.

Out of the commercially available units, for instance, the pump controller CC1-LCD of COMAC International company can be selected [COMAC 2016]. It is used to control the liquid level. The level state is measured by means of dynamic pressure, saturation by the air bubbles, an external sensor (4- 20 mA) or a float switch. Furthermore a controlling module ESH21 can be mentioned which is manufactured and supplied by Eledo company [ELEDO 2016]. It is an engine pump controller with the sensing of the levels, with a built-in acoustic alarm of engine failure and maximum levels which can be placed into the junction box on a DIN rail. A combined level sensor is designed for the automatic control of pumps for sewage and other polluted environments of conductive liquids where there is a danger of contamination of the sensing elements. The regulators Grundfos LC 220 are specified to control the sludge pumping stations, such as Multilift MSS or Unolift [GRUNDFOS 2016]. The level control unit enables or disables the pump according to the liquid level measured by piezoresistive level sensor. When the start level is reached, the pump turns on and when the liquid level is lowered to the stop level, the pump is stopped by the regulator. The alarm is activated in case of high water level in the tank, sensor failure etc. The recording and the control unit of M4016 type was created in the FIEDLER AMS company [FIEDLER 2016]. Two major water companies also contributed to its development with their requirements and so the result was the creation of the devices with a wide use in many applications. The M4016-G unit incorporates in full equipment the universal data logger, telemetric station with a built-in GSM / GPRS module, programmable controlling robot, PI regulator and, in connection with ultrasound or pressure level sensors and a multiple flowmeter. In the M4016-G unit it was possible to combine its easy software and hardware modifiability as well as its high resistance to adverse conditions in which it often works. The unit can be expanded with a range of external modules with which a customer can considerably modify the measuring set. There are 16 (up to 32) dynamically

filled recording channels for measuring and archiving of the flow, levels, pressure, and many other variables. The pump operation and failures, the disruption of the object or general states of contacts can be monitored by 40 digital channels. One text channel records all extra incidents, including the received and sent SMS or a failure in supply.

The above mentioned control units are used for controlling the pumps in low pressure sewer networks. Depending on the manufacturer and the buildings they are designed either for the direct connection to pumps or to controlling of switching elements of the pumps. Some of these units include advanced diagnostic functions, including messaging via the GSM network. None of the above described units enables the remote control of the subordinate technology depending on specific operating states of the entire system of a low pressure sewer network. Also among them it is counted with mutual cooperation in the operation of a low pressure sewer network as a whole. For this reason, it was necessary to develop a completely new control unit which will ensure functional extensions of the previously used units of the possibility of remote control and synchronization operations.

#### 4 DETERMINING OF THE NEW CONTROL UNIT SPECIFICATIONS

The aforementioned task is solved by designing a new control unit supplemented with the function of automatic flushing and synchronization. The properties of the presented unit are based on the operational requirements of a low pressure sewer network. During a normal operation of the system of a low pressure sewer network the pipe sections may occur in the network where it is practically impossible to achieve the required flushing speed to ensure a self-cleaning effect in the pipeline. It is due to the fact that there is no parallel pumping of individual pumping stations and the water flow velocity in the pipeline is constantly low, thereby clogging the system. A possible solution is to cause a regular flushing speed at which the required flow in the pipe system will be realized. To cause such a flushing speed it is needed to synchronize the pumping of individual pumping stations. In terms of operation, the synchronization can be solved by communications between the units. It is possible to apply an operation model of one master control unit and more subordinate units (master-slave operation). In the case where it is not possible to carry out the communication between the units, the units can be operated autonomously according to a predetermined schedule or the last operating mode. To calculate the optimal time to start the impact wave a computational model of a low pressure sewer network is used [Rucka, 2015], which predicts a continuous state of fulfilment of pump sumps where the waste water is accumulated before pumping. Consequently, it is able to optimize the moment of synchronized pumping start with respect to the effect achieved while maintaining the required network reliability. The computational model of a low pressure sewer network communicates with the control units via a specially created interface implemented in the units.

The design of the developed unit is based on the functional requirements of already implemented systems of low pressure sewer network. A future unit must have digital inputs and outputs for processing the signals from sensors and to control the performance section. Analogue inputs for measuring continuous variables. Then it must be able to communicate with the master unit which will provide the cooperation of activities of the entire system. It represents full mechatronic system [Andrs 2011], [Andrs 2013], [Hadas 2012], [Holub 2015].

The designed control unit includes the following basic parts:

- A master unit which can be expanded with additional inputs and outputs with additional modules; it also includes a communication interface (e.g. Ethernet), with the help of which this unit can be connected to the rest of the control system (other pumping units); another function of the unit is reserve of power supply with real-time clock and the last operating parameters; the unit is also equipped with a display for displaying of operational values and manual controls
- Wireless communication module equipped with an interface, for example, GSM, GPRS, GPS
- Power module to provide the power for all components
- For monitoring of operational states of the pump in terms of current sampling the measuring underflow and overflow module is used which depending on the operating state monitors the flow drawn by the pump
- A module for connection of a level pressure sensing
- Module for the sensor connection of the technology of the pump sump (e.g. float sensors, measuring electrodes, etc.)
- Module of power pump control

The main characteristics of the developed system controller of flow pressure sewer network with the automatic flushing are:

- The level measurement using a pressure sensor, float sensor or measuring electrodes with the possibility of extension for any sensor with a digital or analogue output (the evaluation of four levels: sensor without water, lower level, upper level, pumping reserve)
- Evaluating of the correct flow drawing by the pump while operation or during a shutdown
- Four operating modes: turned off, exhausted up to limits of the lower levels, maintaining the level between the upper and lower limit levels, automatic inlet of supply water for flushing in the specified time and date (alternatively repeatedly)
- Short-term cyclical turning on of the pump every day to prevent its stiffening
- counting of working switching of the pump
- Counting of the operating hours of the pump

The considered unit can be block depicted by Fig. 5

Level measurement in the sump can be realized by using the differential pressure sensors which are connected to the

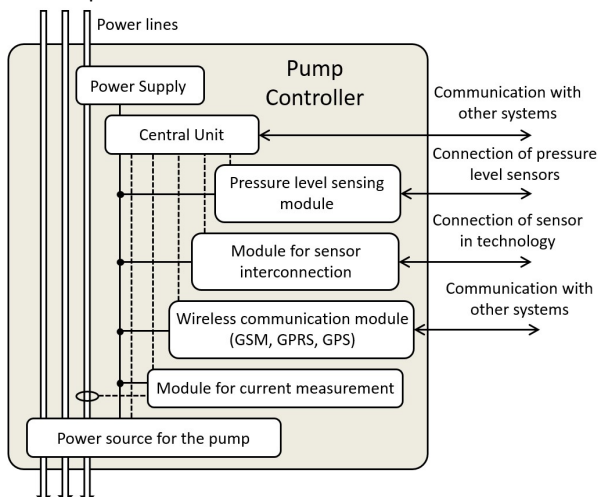


Figure 5. Block scheme of the instrumentation of the control unit

pressure hose leading to the pump sump. The pressure hose is placed below the surface of the pumping liquid and is stretched with special weights.

## 5 DEVELOPMENT AND EXPERIMENTAL VERIFICATION

To verify the design of the basic instrumentation involvement and the development of the controlling application a laboratory test prototype was drawn up (Fig. 6) on which it is possible to demonstrate alternative operating conditions of the considered device. The test device consists of a vertical pipe filled with water which directly simulates the water column in pump sumps. It is also equipped with a miniaturized pump powered by a DC motor from a laboratory source of safe voltage. These components replace a real system of a pumping sump and a pump. The pipeline of the test device is chosen with a small inner diameter because of the reduction of the amount of liquid in the test device and with regard to the performance of the miniature pump. A smaller amount of the pumped liquid during the simulation experiments reduces the time and energy performance of the tests. The connecting of additional instrumentation corresponds to the planned acute deployment with the only difference that the mounting was done not in the distribution boxes, but on the development board, see Fig. 6.

The functionality of the implemented algorithms to control a single unit and communication between the units in a master-slave mode has been successfully tested on the development board. With the help of the test prototype the entire assembled system was tested in all the suggested modes. Test results confirmed the possibility of proceeding to the next development step which is the installation of the entire instrumentation to the distribution box which will be placed into actual operation of a flow pressure sewer network in one of the case studies which are involved in the project.

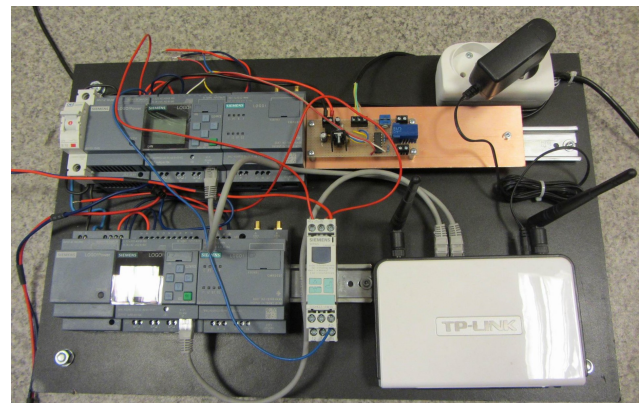


Figure 6. The connection of the controllers on the development board

## 6 SUMMARY AND CONCLUSIONS

While the practical operation of low pressure sewer network systems, many typical faults and malfunctions occur. Some of them can be solved and removed relatively easily, for example, by replacing a dysfunctional pump, cleaning or replacement of a level sensor, etc. One of the less common, but worse removable defects of a low pressure sewer network is clogging of the pipe by the sediments from wastewater. The optimal approach is to prevent this phenomenon. It is also remembered by the relevant standard EN 1671 which imposes an obligation to ensure in every section of a low pressure sewer network at least once a day a minimal flushing speed which will ensure a self-cleaning effect of the pipeline. In practical operation, pipe sections still can be found where this condition is not fulfilled and the clogging occurs. The solving of an unsatisfactory state is

offered by a newly developed pump controller of a low pressure sewer network which can automatically synchronize the pumping of more pumps in the system, so as to create the required flushing flow and cleaning of the pipes. This unit can also be equipped additionally in the place where the pipe clogging occurs, thereby optimizing the operation of the entire system. Currently, this control unit is in the last phase of laboratory testing before the installation to real operation.

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#### CONTACTS:

Ing. Jan Rucka, Ph.D.  
Brno University of Technology  
Faculty of Civil Engineering  
Institute of Municipal Water Management  
Zizkova 17, Brno, 602 00, Czech Republic  
Tel.: +420 604 794 350  
email: [rucka.j@fce.vutbr.cz](mailto:rucka.j@fce.vutbr.cz)  
[www.vodabrno.cz](http://www.vodabrno.cz)

Ing. Ondrej Andrs, Ph.D.  
Brno University of Technology  
Faculty of Mechanical Engineering  
Department of Production Systems and Virtual Reality  
Technicka 2896/2, 616 69 Brno, Czech Republic  
Tel.: +420 541 142 485  
email: [andrs@fme.vutbr.cz](mailto:andrs@fme.vutbr.cz)