New Monitoring Methodology for Water Distribution Systems

Erwin Kober*, Gerald Gangl*

*RBS wave GmbH, Kronenstraße 24, 70173 Stuttgart, Germany , e.kober@enbw.com; g.gangl@rbs-wave.de

Keywords: Monitoring System; Virtual DMA; Water Loss Reduction

Abstract

From technical, economic and ecological aspects the reduction of water loss is becoming more and more important for water supply companies. With the available technologies such as noise measurement and the correlation method, locating and pinpointing of leakages is unproblematic. The actual problem is to set up a monitoring system which allows the identification of new or developing leaks very early and to localise these leaks. As state of the art, the IWA emphasise a separation of the distribution system into DMAs with a fixed boundary in the context of measuring the inflow rate. Disadvantages like stagnation or reduction of the hydraulic performance can be the result. In this context, EnBW developed a inexpensive system for monitoring water distribution systems as an open network system without DMA. LeakControl is a measuring system which is based on ultrasonic flow meter and uses GPRS/GSM for the transmission of the data. The LeakControl sensors which are installed in hydraulically relevant positions (pipes) are spread over the network and measure differences in the minimum night flow rate compared to reference values. Analysis of the measured data allows the localisation of the leak position in an area around the influenced meters also in combination with already installed meters. An adoption to a Scada System can be easily realised.

Introduction

Water loss from distribution systems is a problem in almost all conurbations around the world, but can be a serious issue in areas where water is scarce. To avoid water loss and save water resources is a continuous and important task for every supply company.

Even in highly developed industrial countries with a water supply system in good condition and low water loss like Austria, Switzerland and Germany, the maintenance of systems and the reduction of water loss are becoming more and more important. But even in those countries the pipe systems have become much older and vulnerable to damage which will lead to an increase in water loss.

Especially for an efficient management of supply and rehabilitation, the knowledge of failure rate and water loss is important for indication of the system condition.

In order to quantify water loss and to determine methods for reducing loss, a reference level or a limit level is necessary. National and international associations (IWA, DVGW), have published performance indicators and reference levels, whose calculation is influenced by several different input factors. The results should support and inform the water supply company about the actual condition of the supply network and make it possible to establish methods for the reduction of water loss.

These methods cannot be compared to financial consideration concerning the water volume saved in short term periods. By not investing in the supply network for reducing water loss over a longer period, a shortage in supplies and hygienic problems might lead to a total collapse of the water supplies.

For an efficient reduction of water loss, EnBW and their technology partners have developed a new monitoring system for water distribution systems.

Identification of water loss

Several methods can be used for identifying water loss, but have to be adapted to the distribution system concerned. Influencing factors like network structure, materials used or diameters have to be taken into consideration.

The Water Loss Task Force WLTF of the International Water Association has been focusing on the topic of finding leakage and water loss reduction for several years. As an approach step by step the WLTF proposes the LLP-Methodology:

- Localise
- Locate
- Pinpoint

"Localise" stands for a method of narrowing down the location of the leak, "locate" stands for a method of locating the region of the potential leak within a area of $\pm$ 300 m and "pinpoint" stands for a method where the exact location of the leak is located prior to excavation. If the operator is skilled enough or uses the equipment correctly, then pin-pointing is normally within a range of $\pm$ 300 mm (Hamilton, 2007).

Measuring methods

For detecting water lost from leakage, in principle three main methods can be used:

- flow monitoring
- pressure monitoring
- noise monitoring

Flow monitoring

For flow measuring several methods are common such as mechanically based water meters used for service connections, ultrasonically based flow meters or magnetic inductive flow meters. Water leaking from a break causes a change in the flow rate (velocity) and flow volume, which is compared to a reference value; thus a leak can be detected.

Pressure monitoring

The water in the pipe causes pressure on a membrane where the pressure can be measured. When no water is used, the pressure is balanced to the hydrostatic pressure level, flowing water reduces this level. Water leaking from a break causes a change in the flow velocity and pressure, where compared to a reference value; in that way a leak can be detected.

Using this method, only major damages will be identified, because small leakages will not result in a significant reduction of pressure.

Noise monitoring

Water leaking from a break causes sound waves, which can be detected in the surrounding area of the leak. Depending on material and diameter the oscillation of these waves is very high or very low. The basic requirement is that the material is allowed to swing. For metallic pipes sound waves are normally easily detected, systems constructed with polyethylene pipes will cause problems because the pipe material is highly noise-absorbing (Heydenreich & Hoch, 2008).

Water balance

A simple way for quantifying the volume of water loss is to calculate a water balance. The system input volume is compared to the authorised consumption. The difference is the amount of water loss, which can be split into apparent and real loss. The International Water Association has published a template to calculate water balance (Lambert & Hirner, 2000).

A correct and comprehensive measuring of the system input volume and the volume of water used is an integral part of water loss calculation. A continuous monitoring requires a continuous measurement of the relevant data of each district, like inflow, pressure or water level in a storage tank. (DVGW W 392, 2003).

The measuring of the system input and the water used is a necessity for a significant water balance. Measurements with less accuracy lead to an insecure result concerning the question if a water supply utility is in good or bad condition (Gangl et al, 2007).

Some of the input parameters for calculating a water balance are estimated on the basis of experience; others are calculated by using reference levels of guidelines (DVGW W 392, ÖVGW W 63) as a percentage of the system input or of the measured consumption (e.g., the apparent loss). A water volume balance is always based on the comparison of system input, i.e. water transferred through the system, compared to water used within a district with fixed boundary. According to regulations (DVGW, ÖVGW) an annual calculation of a water balance is necessary.

On the basis of the water balance the specific water loss in m³ / (h x km) can be calculated for further considerations (DVGW W 392, 2003).

Common monitoring methods

When calculating a water balance for a complete supply system, changes in the annual system input and annual volume of water used can in general be described. For a detailed analysis and for finding weak points in the network a water balance over the whole system is not adequate. The calculation of an annual water balance is based on a comparison to the past. For that reason a reaction is delayed. Only by continuous monitoring, may leakage be localised and the period of time elapsed between occurrence and repair can be reduced.

District metering

The IWA (International Water Association) proposes to separate the distribution system in district metered areas - DMA. A district metered area is an area with strict hydraulic boundaries within a distribution system with measured inflow in each district. The measured night minimum inflow is compared to the customer’s night consumption to calculate water loss (Morrison et. al., 2007).

The advantage of a hydraulically separated area is to measure the system input easily by clearly defined input flow meters. By closing valves the points of inflow are clearly defined. When considering the minimal night flow, the change in inflow will picture the growth of a leakage (Figure 1).

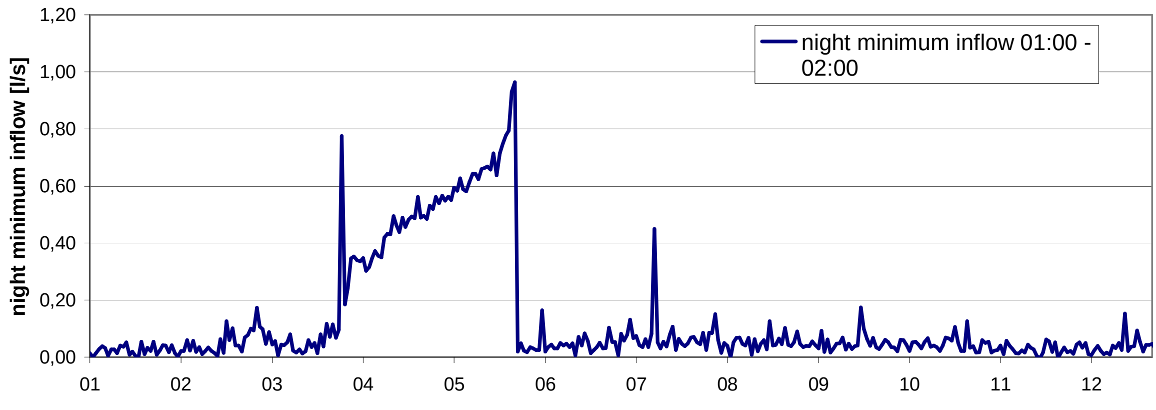

Figure 1 Graph of the night –time minimum system inflow of a small DMA (repair of failure on 3rd June)

According to the DMA Guidance Notes (Morrison et. al., 2007) a district should have between 500 and 3.000 service connections. When a DMA is too large, changes in flow rate (velocity) measured with an inflow meter can be hardly identified. With an increasing volume of the system inflow, the probability of identifying even smaller leaks with system inflow only, measurement is decreasing.

When there is a lack of information regarding the hydraulic condition, as well as the flow or pressure situations, a separation into districts with strict boundaries is a simple and efficient method to get an overview of the actual condition. This leads to a possibility to classify water loss by water balance (Kober, 2007).

The disadvantage of district metered areas is the separation into hydraulically discrete areas. When a break occurs in an open network, a supply of the customers is normally possible, water can flow through the surrounding pipe sections to the customers. The water supply needed in cases of fire fighting can also be better secured in an open network, because the hydrant gets its water from the surrounding pipelines. Creating discrete areas with strict boundaries can result in zones with stagnation, reduced flow velocity and higher retention time with sedimentation or hydraulic problems.

Monitoring with noise loggers

When using noise loggers, the acoustic level caused by the leaking water is analysed. For monitoring, these loggers are positioned either permanently or temporarily within a metering area. Measurable leak noises, dependent on the pipe material and pressure, only occur in the direct surroundings of a leak and the available technologies are applicable only for the detection of the leak itself, or to contain the leak area. For the early detection and localization in bigger networks or network districts noise loggers are not applicable.

In metallic pipelines the distance between the loggers can be up to 200 m. When used on non-metallic materials the distance decreases to 80 – 100 m (Heydenreich & Hoch, 2008) depending on the circumstances (e.g. pressure).

The advantage of these measuring instruments is the easy monitoring of a network with less staff. With a remote readout, the stored data can be collected with a vehicle driving past. In a distribution system with a high percentage of metallic pipes this method has economic advantages.

The disadvantage of this method is that the noise of the leak has no direct connection to the volume of water loss. A very small leak with a high leaking noise is detectable, and will be promptly repaired sooner instead of later on together with other planned construction works.

Another disadvantage is the usability for non-metallic pipes as explained before. With a higher percentage of non-metallic materials in the network, the number of noise loggers is increasing and the economic advantage is decreasing.

For a temporary monitoring in a district metered area, where the volume of water loss of a leak is considerable, these loggers are easily installed and produce good results in localisation of leaks when using the required quantity of loggers.

Monitoring of an open network without DMA

So far it, has been explained how the described monitoring systems used for drinking water distribution networks have limits. For that reason, the effectiveness and economics of each method has to be proved.

The goal of the engineers of EnBW (Energie Baden-Württemberg) and their subsidiary RBS wave was to develop a modern monitoring system based on ultrasonic flow meters which allows continuous metering for early detection and localisation of leaks. Using this technology, an immediate reaction is possible and should reduce the expenditure for localisation. Hence, the required standards of the German guidelines or those of the IWA for reducing water loss are fulfilled.

To apply this system for all pipe materials, the measurement of flow was identified as the crucial indicator. To meter flow rates (velocities), and their changes is a practical, precise and robust technique.

This method is not based on calculating water balance; the parameter for indicating water loss is the change in the flow rate (velocity) in an open network without strict boundaries. No structural change in the network is necessary. As a basic requirement for the implementation, information about the hydraulic condition is necessary to make an optimal positioning of the flow meters.

General procedure

The basic methodology is to continuously measure the flow rate (velocity) at several points and compare the metered data with reference values. When measuring the night minimum flow, a comparison with former metered data allows calculating if new leaks occur.

If the system is not divided into district metered areas the meters have to be positioned at hydraulically relevant positions (pipes) over the distribution system to meter conspicuous changes in the flow velocity. If these conspicuous changes are stable for more than two or three days (nights), this change is based on a leakage and not an influence of customer habits. This change in flow velocity is metered by the installed measuring instruments regarding to their hydraulic position (closeness) to the leak. With the strategic position of the sensors in the network, virtual DMAs are introduced between the sensors. Analysis of the influenced meter spread over the distribution system results in a first rough estimation of the localisation of the leak (Figure 2).

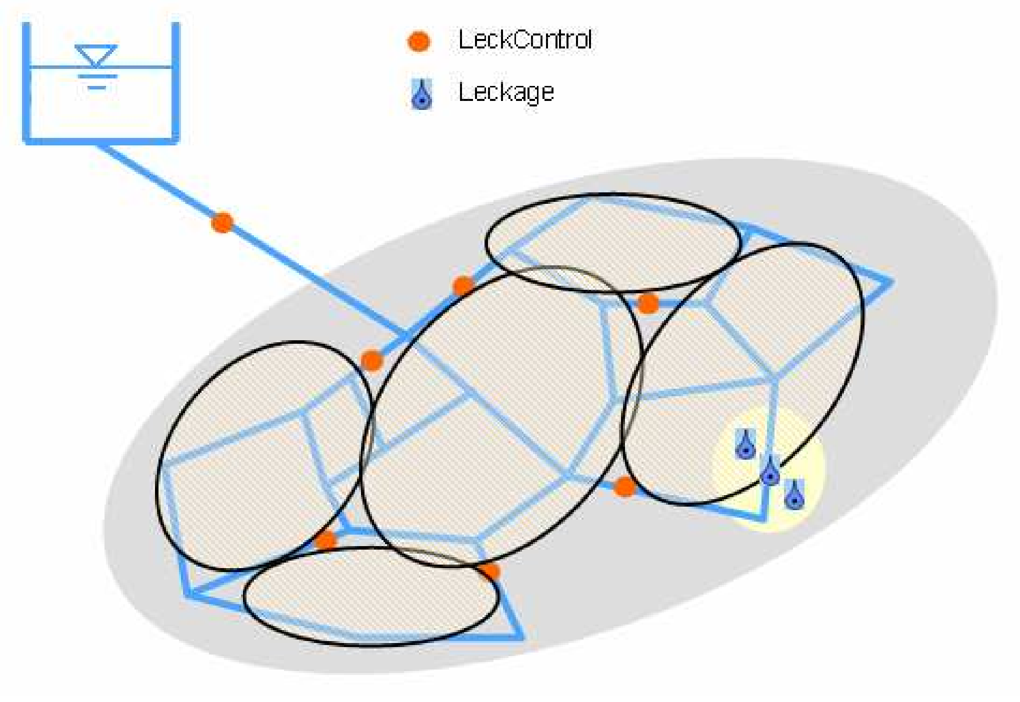

Figure 2 localisation of a leak in a virtual DMA

When the distribution system is separated into several district metered areas, the actual installed inflow meters can be used as a support for the monitoring system. In large DMAs where small leaks have less influence on the district inflow, additional flow meters are necessary for a consistent and continuous monitoring of the system.

For a combination of existing DMA inflow meters, like magnetic inductive flow meters and further LeakControl sensors for detailed analyses, SIEMENS has developed the water application software SIWA^{CIS}LeakControl for multiple -stage analyzing, reporting and alarming, using the widespread standard software package SIMATIC WinCC as HMI. In a case study at Stuttgart waterworks, a combination of installed magnetic inductive flow meters and additional installed LeakControl ultrasonic flow meters is realised within the existing Scada System. The idea was a subdivision of large DMAs into smaller monitoring sections without any hydraulic constraints.

Within the EnBW monitoring system the minimum night flow is analysed, where leaks can be identified more easily. The lower boundary of the measuring span of this modern sensor is about 1 cm/s and allows metering of very slow flow rates (velocities), too.

With the installation of the meters on hydraulic relevant positions over the distribution system, it is possible to describe the flow characteristic of an open network without districts. Changes in the minimum night flow are identifiable.

When a leak occurs, it will be identified by the installed flow meters and localised on the basis of the positioning of the influenced measuring instruments (virtual DMAs). For locating and pinpointing instruments like noise loggers, correlators or other methods can be used.

Measuring method

An ultrasonic flow meter offers an inexpensive and precise measuring process; the possibility to meter the flow velocity by a transit time technique. For the measurement, two ultrasonic pulses are sent through the medium, one in flow direction, and a second one in opposite direction. The transducers alternately work as emitter and receiver. The transit time of the ultrasonic signal propagating in flow direction is shorter than the transit time of the signal propagating against flow direction. The transit-time difference Δt is measured and allows the determination of the average flow velocity on the propagation path of the ultrasonic signals. A profile correction is performed to obtain the average flow velocity on the cross-section of the pipe, which is proportional to the flow volume. By measuring 1,000 values per second and a statistical correction of freak values, the metered values show high precision.

Installation

To realise an effective and economic installation of this monitoring system under operation, the decision was to use flow meters which can be fixed on the existing pipe. Next to the advantage of the high precision of the flow meter another advantage of the ultrasonic flow meter is the possibility to use a clamp-on technique. At no time it is necessary to drill or cut the installed pipeline. The sensors can be installed in a manhole or directly on the buried pipe or can be installed with a special sluice without the necessity of a manhole.

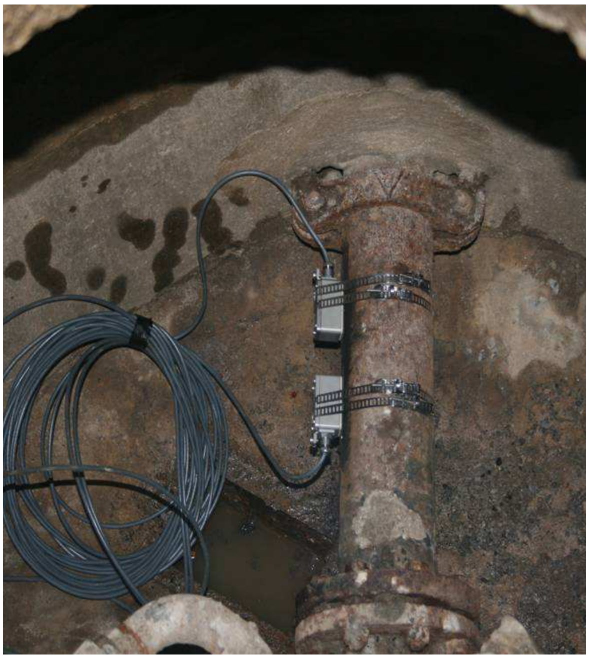

Figure 3 installation of LeakControl in a manhole

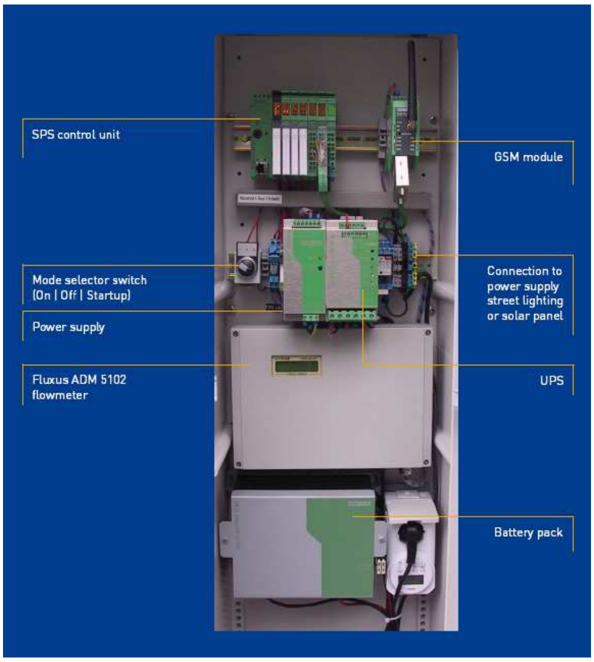

Figure 4 control unit

For power supply a connection to street lighting or alternatively a solar panel is necessary. A minimum power supply of 4 hours of street lighting is enough to meet the energy requirement. A sufficient cellular network is essential as well, because the flow data will be transferred via GSM or GPRS to a PC / laptop, where the data can be analysed. Using the Siemens Interface the data can be transferred to each Scada System.

Analysis of the metered data

With the analysis of the metered data the weak points and leaks in the network can be localised. The first implementation measurement is defined as the basic condition and reference value including all present loss. When the basic reference value is reduced by repair of leaks or rehabilitation of pipelines, the level of background leakage has to be reduced. If conspicuous changes in the night flow are stable for more than two or three days, this change is based on a leakage and not on an influence of customer habits. To achieve high accuracy the flow meter should be measured in close time steps. For evaluation of the metered data to find key aspects for activity, average values of the 5 smallest values in a minute excluding peak values caused by customer consumption.

For accurate analysis, data of at least one hour at the same time are necessary for comparison. In some distribution systems water is pumped from wells through the distribution system in storage tanks during the night time, and a minimum night flow cannot be seen. With a change of the pump control or a break of filling the storage tank for one hour, enough data can be collected to get an accurate evaluation. Therefore also in systems with intermitted supply, this monitoring methodology can be used if the system is pressurised for at least one hour.

Case study

Adapted to the hydraulic situation, in 2003 six sensors were installed in a network with a length of 40 km. According to the German regulation DVGW the water loss was in the category of “high loss” with 0.178 $m^3/(km*h)$. Since the installation of the sensors it has been possible to reduce water loss to a level of middle loss with 0.091 $m^3/(km*h)$ in 2007. The main reason for reduction of the loss was the reduction of time elapsing between the occurrence, detection, and localisation of the leaks.

Figure 5 shows the occurrence and the growth of the leak. By using the average smallest flow values, the influence of flow peaks can be reduced.

Figure 5 analysis of measured data

For an ongoing reduction of water loss the infrastructure management has to change from a single repair strategy to a foresighted rehabilitation strategy to upgrade the general network condition.

Conclusion

For monitoring and measuring water loss in a distribution system, several methodologies are common, which are influenced by material, diameter or other factors. The advantages and disadvantages have to be taken into consideration to find the optimal technique for water loss management in the respective supply system.

According to the long experience of EnBW and RBS, work in their own network and based on services to the systems of other companies, a monitoring system was developed which can be used for all materials, diameters and network conditions. With metering instruments providing data of high accuracy, a prompt analysis of the data is possible.

The idea of the monitoring methodology is to measure changes in the minimum night flow without the necessity of discrete districts. In several smaller and medium water supply utilities in Germany this method is realised. In larger water distribution systems (zones) or specific supply conditions it might be necessary to separate the system into DMAs. With the connection of data from existing flow meters and additionally installed LeakControl flow meters, the identification and localisation of leaks is simplified.

The monitoring-system as presented in this paper is realized in 8 German water supply utilities including the city of Stuttgart, the implementation in further water supply utilities is planned.

References:

Gangl, G., Kölbl, J., Haas, G., Hassler, E., Fuchs-Hanusch, D., Kauch, P. (2007) Influence of Measurement Inaccuracies at a Storage Tank on Water Losses, IWA Conference Water Loss 2007, p. 474 - 484

Gangl, G., Dietz, R., Sacher, J. (2009) Leckagenfrüherkennung am offenen Versorgungsnetz, Energie-Wasser-Praxis 3/2009

Hamilton, S. (2007) acoustic leak detection. www.iwaom.org/wltf

Heydenreich, M., Hoch, W. (2008) Praxis der Wasserverlustreduzierung. *DVGW*, Bonn, ISBN 978-3-89554-171-1

DVGW W 392 (2003) Rohrnetzinspektion und Wasserverluste – Maßnahmen, Verfahren und Bewertungen. DVGW, Bonn

Kober, E. (2007) Sustainable reduction of water loss in urban water distribution systems, , IWA Conference Water Loss 2007

Lambert, A., Hirner, W. (2000) Loss from water supply systems: Standard terminology and recommended performance measures. *IWA Blue Pages*, London, UK

Morrison, J., Tooms, S., Rogers, D. (2007) District Metered Areas Guidance Notes. *Draft 2/2007 - Version 1*, www.iwaom.org/wltf

ÖVGW W 63 (1993) Wasserverluste in Versorgungsleitungen, Anschlussleitungen und Verbrauchsleitungen – Feststellungen, Beurteilung und Maßnahmen zur Verminderung. *ÖVGW*, Wien, www.ovgw.at