Evaluation of sensors for monitoring temperatures in district heating pipes

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1 Introduction

The insulation of district heating pipes (DH-pipes) underlies a slow degradation. Therefore the heat loss increases with time.
Environmental conditions around DH-Pipes can vary in a big range and can also change quickly e.g. trough changing soil moisture content. This leads to the fact that the isolation degradation is hardly predictable.
A way to identify the degradation individually for every DH-pipe would be to include temperature sensors into the pipes to monitor the actual heat loss.

The goal of this evaluation is to give a brief overview about different monitoring possibilities.

2 Sensor-Systems

It is necessary to differentiate between wired and wireless solutions.
With wired solutions the sensors are supplied with energy and read using a wired connection whereas wireless solutions use radiation instead of cables for the same purpose.
It is also possible to use a semi-wired approach where e.g. a sensor is wired with a power supply but the sensor communication works wireless.

In case of DH-pipes only fully wired or wireless approaches are taken into consideration.

2.1 Radio-frequency identification

Radio-frequency identification (RFID) is used for identifying and tracking tags attached to objects using electromagnetic fields.
Active (semi-wired) and passive systems (wireless) are available in different standard frequencies. Those are Low-Frequency (LF, 135 kHz), High-Frequency (HF, 13,56 MHz), Ultra-High-Frequency (UHF, 868 resp. 915 MHz) and Microwaves (2,5 resp. 5,8 GHz).
Reading sensors and not only identification numbers is also possible with RFID. One example of an integrated circuit measuring temperatures using HF-frequency is the *MLX90129*[1] (Melexis, Ieper, Belgium).

With an increasing frequency the penetration of water sinks clearly (Kern, 2011). The damping at 100 kHz is for water or non-conductive materials about factor 100000 lower than at a frequency of 1 GHz (Finkenzeller, 2012). Britz et al., 2012 shows that even the readability of HF- and especially UHF-tags mounted on plant pots filled with wet soil decreases. Because of that conventional RFID-systems with frequencies of 13,56 MHz and higher probably don't work with tags buried in around 60 cm depth where DH-pipes are located usually. Therefore the usage of low frequencies is desirable for penetrating soil.
According to $\Delta E = h \times f$ the energy transmitted with lower frequencies is lower. Because of that lower frequencies require bigger antenna sizes and a lot more transmission power for achieving the same operating distance as higher frequencies.
Currently there are solutions available for identifying buried pipes (see 3M, 2012 & 3M, 2013). The smallest marker (ibid.) has a diameter of 10.4 cm which visualizes that even for just tracking an identification number the antennas need to be rather huge compared to commercial RFID-tags used in logistics. According to a manual of a suitable locator the highest used frequency in those systems is a non standard frequency of 200 kHz (3M, 2009).

All in all it would be possible to develop a system for monitoring temperatures in DH-pipes using passive RFID-technique, but it would require big antennas buried with an optimal orientation. Also there would be the need to actively walk along the pipes for reading sensors.

2.2 1-Wire

The 1-Wire bus was originally designed for communication with nearby devices on a short connection, but today it is usable for sensor networks with a length of more than 500 m. With a 1-Wire bus are different topologies possible (linear, stubbed and star). For long distances it is absolutely recommended to use Category 5, twisted-pair copper wire. (Maxim Integrated, 2008)
The bus needs only two wires using parasitic power supply, but the optimum is achieved using three wires (supply voltage, ground and data). For short distances (depending on

[1] `http://www.melexis.com/Asset/Data-Sheet-MLX90129-DownloadLink-5941.aspx` : 2016-04-12

the environment) it is even possible to use unscreened and unpaired wires.
Especially when using 1-Wire over a long distance the voltage loss depending on cable type and length must also be taken into consideration.

There are several sensors available on the market. For example with the *DS18B20 sensor*[2] (Maxim Integrated, San Jose, USA) is a calibrated sensor with an accuracy of ±0.5°C between −10°C and +85°C at a measuring range from −55°C to +125°C available.
Every sensor has a 64-Bit unique identifier. The maximum count of sensors in one network is depending on several factors like type of power supply, cable type and length and must therefore be calculated individually.
The 1-Wire protocol is patented. This could be a drawback if own sensors shall be developed.

In total the 1-Wire bus seams to be suitable for monitoring temperatures in district heating pipes if using a high quality cable. It is easy to implement as everything necessary is available on the market.

2.3 Controller Area Network

A Controller Area Network (CAN) bus is an industrial field bus developed by Robert Bosch GmbH, Gerlingen, Germany.
The definition of a CAN bus describes the physical conception like the data frames and the timings, but no protocol. So to speak it defines something like Ethernet which needs e.g. TCP/IP which is the protocol.
A CAN bus should be operated using screened cables with twisted pairs. Normally two pairs are used if the power (standard = 24 V) for the nodes shall be supplied through the CAN bus. It is recommended to use at least one twisted pair and one single wire. So it is possible to use symmetric signal transmission which makes the CAN bus very robust against distortions. However it is also possible to use the bus only with two wires ("Single Wire CAN").
A standard CAN bus allows only a line terminology and needs termination resistors on the ends of a bus line.
Up to 5000 m bus length are possible. The maximum data load is 8 Byte per message. The number of participants depends on the used identifier (11 bit or 29 bit) and the protocol. For example with a protocol named CANopen 127 nodes are possible using 11 bit identifiers. (frenzel + berg electronic GmbH & Co.KG, w.y.)
Using a custom protocol up to 2^{29} nodes would be possible in theory.

[2] https://datasheets.maximintegrated.com/en/ds/DS18B20.pdf : 2016-04-12

There are only few temperature sensors available using a CAN bus. Therefore it is probably necessary to build a custom CAN bus sensor. The following parts might be necessary for this task:

1. CAN bus enabled micro-controller
2. CAN transceiver
3. Any digital or analog temperature sensor
4. DC-DC converter
5. Passive parts (resistors, capacitors...)
6. Conductor board

3 Conclusions

In general it is necessary to decide whether a wireless or a wired solution is desired.
A wired solution gives the possibility to log all sensors permanently from one position but is maybe more critical in terms of corrosion and a system black-out. In contrast to that a wireless solution requires a manually reading of every sensor but there is no risk for a system black-out if the hardware was designed properly.

RFID generally would be usable for monitoring DH-pipes. But as no solution is available on the market it would be necessary to engineer an own system. The required antenna size might be a limiting factor.

1-Wire would also be generally be usable for monitoring DH-pipes but as the length is limited and as it never was developed as a real field bus it is only recommended to use for laboratory tests. Here it has the advantage that it can be set up very quickly because all essential parts are available.

The CAN bus is definitive the most reliable system mentioned in this evaluation. Screened cables with symmetrical signals allow long bus distances and a custom protocol could be used. So monitoring possibilities are nearly unlimited. It would absolute be worth to engineer an own CAN bus temperature sensor.

All in all every system has advantages and drawbacks. Depending on the focus the most suitable system may differ.

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