MONITORING OF BRIDGES CORROSION LEVEL

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Abstract: Corrosive damage level of bridge constructions becomes high discussed topic with regard to some recent incidents. Current system of inspections is based mostly only on visual inspections in the Czech Republic. Our solution proposes to build-in a humidity sensor inside a bridge structure to detect leaking water and damage level during long period. Text focuses on description of basic principles of humidity measurement and performed experiments with sensors implemented in porous material showing possibility of measurement inside a structure. Finally, a market research of commercially available sensors is documented with narrowing selection suitable for this application.

Keywords: corrosion, damage level, bridge, humidity, water, sensor

1 INTRODUCTION

In last years, a corrosive status of bridges is very actual topic, because the key part of a bridge is prestressed tendons [1] and it is important to detect its corrosion in time. Corrosion of prestressed tendons was the most probably reason of collapse of footbridge in Prague, Czech Republic or a bridge in Genova, Italy. Lifetime of bridge constructions is usually designed for period of 100 years, but it becomes several times shorter due to some damage of water insulation or bad process of construction. Nowadays, system of inspections is based on periodical outside visual checking, which cannot completely describe the damage level, especially inside the bridge caverns. [2] When the hydro-insulating layer is damaged on the top side of bridge, the caverns can fill up with water with no leakage and the tendons corrode. [3][4]

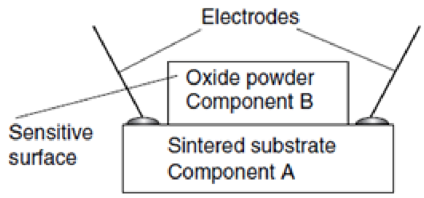
Fortunately, some well-timed findings prevented collapse of some other road bridges, but this method is not sufficient. Placing a moisture sensor inside the construction will provide more information like some weather dependence, season changes and mainly entering of water in the construction during a long period, not only at inspection terms. Therefore, a market survey of available sensors is performed, their key attributes are compared and some will be chosen for new experiments.

2 TYPES OF SENSORS

Moisture sensors can be divided in categories by various aspects. [5][6] By their principle, most common and cheapest are resistance and capacitance sensors. By output of the sensors, they can be divided into analog or digital class. Each of this category has some advantages and disadvantages, which have an impact on parameters and price.

2.1 PRINCIPLES

One of the technically simplest principle is resistive. It uses dependency of resistance of substrate on humidity. The mechanism of changing a conductivity is the water molecules are bound by ions in hygroscopic layer. Harmonic signal is used for measurement to prevent polarization and these sensors work typically in range from 10 to 95 %rh (% relative humidity). Disadvantages of this simple method are lower accuracy and demand on cleanness of water, because some ions in water can affect measuring current. Scheme of resistivity sensor and picture of product are shown in Figure 1.



(a)

(b)

Figure 1: Scheme of resistivity sensor (a)[5] and final product (b)[8].

Second uncomplicated principle is capacitive, where a change of permittivity for different moisture level is used. Permittivity of air is around 1 and permittivity of water is around 80. It depends on material, how much porous it is to obtain as high change of permittivity as possible. A harmonic or pulse signal is used for evaluation of capacity and advantage is separation parts with electrical signal and with absorbed water. The scheme and appearance of sensor is very similar to resistivity type, difference is in electrical detachment of layers. Other types of sensors are based for example on optical principles, spectroscopy, gamma radiation or with optical fibers. These are more complicated, more expensive and often only for laboratory purposes, but final sensors on market are not available.

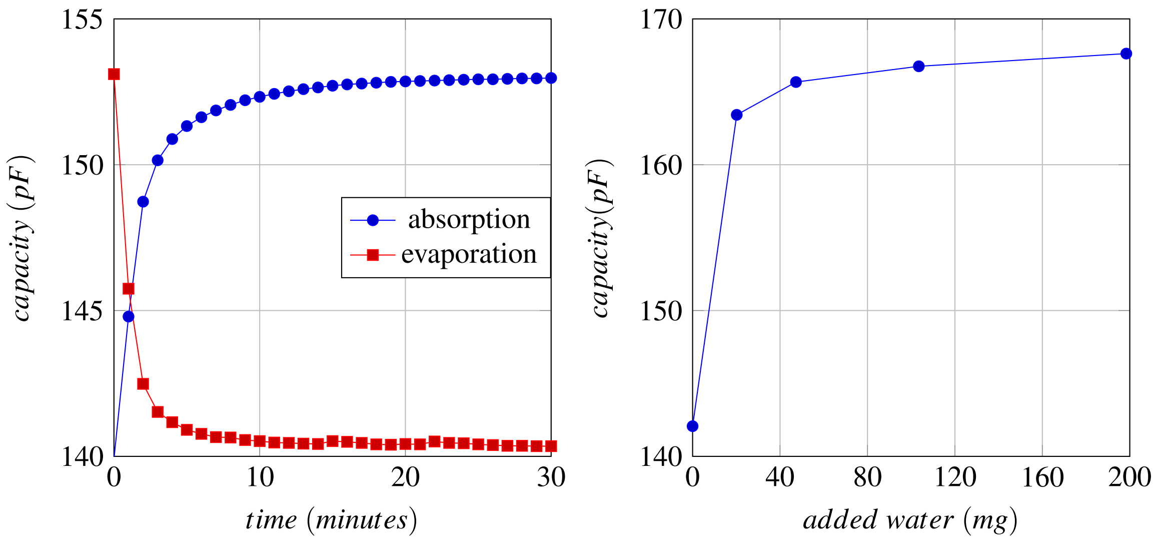
3 PERFORMED MEASUREMENTS

Few years ago, during working on my diploma thesis focused on moister condensation sensors, I performed some experiments with commercial sensors for moisture measurement. [7] These sensors were poured by plaster (gypsum), which is very porous material and makes a permeable membrane. The moisture could still penetrate through and impact is only in longer response time and parameters of sensor remain unchanged. These findings will be applied at this application. In new constructions, sensor will be placed in concrete, but also it could also be placed into older constructions by drilling a hole and sealing off by suitable material.

For experiments I used few sensors based od resistivity and capacitance principle. Resistance sensors showed as unsuitable due to long response time (few days, it could mean chemical reaction instead of response time) and high instability of output. One of applicable sensors was type P14-W made by IST. It has high humidity stability and high chemical resistance, which is one of the most important factors. Sensor was placed in a center of plastic ring with diameter 4 cm and height 4 mm. Empty space was filled with gypsum mixture and its surface was smoothed after dry-off.

By first experiment, sensor was tested on change of humidity from ambient value to 90 %rh. Measured response is shown in Figure 2a and it indicates mentioned longer response time (2 minutes). During second measurement, sensor was exposed to influence of added water. After each addition was made at least 2 hours long pause to allow uniform spreading of humidity in material and to eliminate influence of time constant. Measurement is shown in Figure 2b. Amount of 200 mg added water means absorption of 5 weight % in gypsum surrounding the sensor.

Unfortunately, only few weeks passed since the begin of obtained junior project with Adam Svoboda from Faculty of Civil Engineering, BUT, and it was not enough time to buy new sensors and start any experiments with them. However a market research was done during this period.



(a) Dependency on change of ambient humidity. **(b)** Dependency on added water.

Figure 2: Measured dependencies of sensor.

4 MARKET RESEARCH AND EXPERIMENT DESIGN

Before measurement with new sensors will start, it is necessary to choose some sensors, which will most meet our requirements for this application. Biggest market holders in a field of humidity sensors are Sensirion [9] and Honeywell [10], but also it was attempted to find sensors made by other producers. Sensors were compared from many point of views, some of them were mentioned before like range, accuracy and output. Other features are temperature sensing, response time, price and other aspects.

4.1 Market research

	type of output	operating range (%rh)	accuracy (%rh)	response time (s)	temperature measurement	other	price (circa, €)
Multicomp HCZ-J3-A	analog, resistance	20÷90	±5	NA	N	-	1
SAMYOUNG SYH-2R	analog, resistance	10÷95	±3	45	N	-	1.5
SAMYOUNG SY-DS-1L	analog, resistance	0÷100	±5	5	N	-	2
RADIOCONTROLLI RC-SPC1K	analog, capacitance	0÷100	NA	NA	Y	-	9
IST P14-W	analog, capacitance	0÷100	±2	5	N	-	15
HONEYWELL HIH4000 series	analog, voltage	0÷100	±3.5	5	N	-	20
HONEYWELL HIH4030 series	analog, voltage	0÷100	±3.5	5	N	possible filter	14
HONEYWELL HIH5030 series	analog, voltage	0÷100	±3	5	N	possible filter	10
HONEYWELL HIH6000 series	digital	0÷100	±4.5	6	±0.5 °C	possible filter	7
HONEYWELL HIH6100 series	digital	0÷100	±4	6	±0.5 °C	possible filter	10
HONEYWELL HIH7000 series	digital	0÷100	±3	6	±0.5 °C	possible filter	7
HONEYWELL HIH8000 series	digital	0÷100	±2	6	±0.5 °C	possible filter	8
TE Connectivity HTU21D	digital	0÷100	±2	5	±0.3 °C	possible filter, only SMD	7
SENSIRION SHTW2	digital	0÷100	±3	8	±0.3 °C	only SMD	2
SENSIRION SHTC1	digital	0÷100	±3	8	±0.3 °C	only SMD	2
SENSIRION SHTC3	digital	0÷100	±2	8	±0.2 °C	only SMD	2
SENSIRION SHT30	digital, analog	0÷100	±2	8	±0.2 °C	only SMD	3
SENSIRION SHT31	digital, analog	0÷100	±2	8	±0.2 °C	possible filter, only SMD	6
SENSIRION SHT35	digital	0÷100	±1.5	8	±0.1 °C	possible filter, protective cover, only SMD	10
Texas Instruments HDC2080	digital	0÷100	±2	8	±0.2 °C	only SMD	3
Texas Instruments HDC2010	digital	0÷100	±2	8	±0.2 °C	only SMD	3
Texas Instruments HDC1080	digital	0÷100	±2	15	±0.2 °C	only SMD	3

Table 1: List of some commercially available sensors [8][9][10][11][12]

As can be seen from Table 1, sensors are primary organized by their output, divided in analog and digital ones. Digital sensors provide advantage of conversion of signal directly at the place of measurement in contrast with analog, where some parasitic influences can apply. For this reasons is downer half of the list including sensors with digital output more important. Majority of sensors guarantees operating range from 0 up to 100 %rh, but there are differences for the cheapest types. Unfortunately, not all produces mention principle of sensor. Usually it is capacitance type, but resistivity one could be probably found out and excluded by experiments.

Sensors are also sorted by the producer and series, which corresponds to their accuracy. This accuracy is not valid for full operating range, but usually only for interval from 20 to 80 %rh or other similar. In our application, accuracy is not the most crucial aspect, main attention will be paid to other parameters. The same stands for *response time*.

Next advantage of digital sensors can be seen from following column. All of them have integrated temperature sensor, they provide added information in comparison with analog type. Only one analog is equipped with temperature sensor, unfortunately producer does not specify its accuracy.

Column *other* shows untypical differences, which can influence the final decision. Some sensors offer optional features, like protective cover for eliminating pollution or filter membrane to prevent condensation. Exact income of these options is not described in detail, but considering some pollution of incoming water, any protective layer means advantage. Unfortunately, some of them are available only in SMD package, which complicates their wire connection.

Price of each type shown in the last column, which often corresponds to accuracy of the sensor, has also impact on decision. The effort is to choose sensor meeting requirements for the lowest price. According to some arguments, the most expensive sensors can be removed, because accuracy is not the key factor and they do not provide significant added value. Based on mentioned properties, sensors with digital output will be preferred.

4.2 EXPERIMENT DESIGN AND DATA COLLECTING

Basic idea of the experiment is to make structure as similar as possible to bridge construction and sensors will be placed inside during the production. Exact location will be considered during next period. Since the sensors are not symmetrical, they will be oriented with sensing part downwards to prevent accumulation of water.

There are two basic concepts for the experiments. First option is to make two, almost same test blocks. One will be reference and it will react only to some general changes, but no water should be leaking in it. Second test block will be damaged and it will serve to the main concept, measuring of leaking water. Another option is to make only one test block, perform measurements with good conditions and damage the block for measurements with leaking water. Advantages of the options will be more considered during next periods, until the sensors will be bought, tested and also until a software for measurement will be prepared.

Data collection from I2C sensors is planned by National Instruments I2C interface device, which I used for some data collecting system earlier. Unfortunately, addresses of the sensors will form an obstacle. According to datasheets, sensors from Sensirion allow only 2 addresses (0x44 and 0x45), sensors from Texas Instruments also 2 addresses (0x40 and 0x41) and sensor from TE Connectivity only 1 address, colliding with Texas Instruments sensor (0x40). This limits the number of sensors, which can be autonomously measured and sensor from TE Connectivity will be probably excluded because of the address collision. This problem can be solved by adding a switching device, or a second interface device. Sensors made by Honeywell offer more suitable solution as selectable address in range from 0x00 to 0x7F.

5 CONCLUSION

This text describes current progress of obtained junior project focused on detection of leaking water into bridge constructions. Few older experiments supported idea of installing a sensor in a construction, the surrounding material only prolongs time constant. Some basic principles of humidity sensors are described and market research showed possibility of different sensors in various price categories and some of the have advantage in protecting membranes or filters. These types will be preferred due to possible contamination of leaking water, despite more complicated connecting of SMD parts. They also offer digital output, which is more tolerant to signal interference and also allow temperature measurement. Next experiments include production of a bridge model construction and insertion sensors inside, test their sensitivity on leaking water and their lifespan.

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