

Innovative Technologies and Future Trends in Level Measurement

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Abstract: In recent years, the need for reliable and continuous level measurement in industrial processes has significantly increased. The hydrostatic method, known for its simplicity and accuracy in measuring liquid levels, plays a vital role in ensuring operational safety and efficiency. Alongside this, the FISCO (Fieldbus Intrinsically Safe Concept) approach has emerged as a key solution for enabling intrinsically safe installation of level sensors in hazardous environments. Advanced technologies such as radar, ultrasonic, and electromagnetic wave-based sensors, combined with digital communication protocols like HART and PROFIBUS-PA, allow for real-time data transmission and process optimization. These innovations contribute to enhanced control, resource efficiency, and reduction of potential risks in modern automation systems.

Keywords: level measurement, hydrostatic method, FISCO concept, intrinsically safe installation, process automation, industrial safety, HART, PROFIBUS-PA, radar sensors, ultrasonic measurement, digital communication.

Introduction

In industrial processes, monitoring and controlling the level of liquids and bulk materials is essential for ensuring operational efficiency, reducing waste, and maintaining safety standards. Traditional signaling devices are no longer sufficient to meet the increasing demands for real-time and precise information. Therefore, continuous level measurement instruments have become vital components in modern automation systems. These instruments utilize different physical principles to measure level changes accurately and are designed to operate reliably in various environments, including those with explosion hazards. Companies like Pepperl+Fuchs provide a wide range of level sensors equipped with standard 4...20 mA outputs and digital interfaces, enabling integration with advanced industrial systems. This paper provides an overview of the main technologies used in level measurement and examines their role in the development of smart industrial control systems.

Table 1.1 – Applicability of Various Level Measurement Methods

№ Method Continuous Level Measurement For Liquids For Bulk Solids

1	Hydrostatic	Yes / yes	No
2	Ultrasonic	Yes / yes	Yes
3	Guided Electromagnetic Radiation (Radar, Microwave, Radio Frequency)	Yes / yes	Yes
4	Magnetic Float or Probe-Based Measurement Yes Yes No	Yes / yes	No

1.2- Level Sensor Connection Devices

Nº	Sensor Name	Type / Series	Output Type	Interface / Control Device	Model Designation	Function / Description	Explosion Protection
1	Vibra Con	LVL1-M1 / M2	NAMUR	Safety barrier with transformer	KFA6-SR2-EX1.W	Provides galvanic isolation and signal transmission	Yes
		LVL1-MC2	NAMUR	Safety barrier with transformer	KFD2-SR-EX1.W	Intrinsically safe circuit interface for NAMUR sensors	Yes
2	Conductometric Probe	LKL1-M	NAMUR	Safety barrier with transformer	KFD2-SR2-EX1.W	Converts and isolates NAMUR signal	Yes
3	Magnetic Immersion Probe	LML	Magnetic switch (dry contact)	Safety barrier with transformer	KFD2-SR2-EX1.W	For level switching applications with dry contact outputs	Yes
4	Capacitance Level Sensor	LFLI	NAMUR	Safety barrier with transformer	KFA6-SR2-EX2.W	Signal isolation and explosion protection for NAMUR outputs	Yes
5	Pressure Level Transmitter	MLHC	4–20 mA	Power supply module	KFD2-CR-1300	Powers loop and transmits analog level signal	No
		PPC-M	4–20 mA	Power supply module	KFD2-STC4-EX1	Loop-powered signal transmitter with intrinsic safety	Yes
6	Ultrasonic Level Sensor	LUC	4–20 mA	Power supply module	KFD2-CRG-1.D	Supplies power and transmits continuous level measurement signal	No

7	Radar Level Sensor	LTC	4–20 mA	Signal processor & power module	KFD2-CRG-EX1.D	Intrinsically safe, enables control of max/min level thresholds	Yes
			4–20 mA	Control unit with alarm outputs	DA5-IU-2K-C	Provides dual level limit monitoring with analog output	No
8	Thermal Resistance Sensor	UT-1	Pt100	Temperature transducer & power module	KFD2-CR-1300	Converts Pt100 signal to analog, supplies power	No
		UT-EX1	Pt100 / 4–20 mA	Signal converter with isolation	KFD2-UT-1	Converts resistance to 4–20 mA, intrinsically safe design	No

Level sensors are key instruments used in various industries to measure and monitor the level of liquids or bulk materials. The table includes different types of sensors such as vibrating, capacitive, ultrasonic, radar, magnetic, and thermal resistance sensors. Each sensor type is suited for specific applications depending on the medium, measurement accuracy, and installation conditions. The output signals vary—common ones include NAMUR, 4–20 mA, and dry contact. Interface devices such as safety barriers and signal conditioners (e.g., KFD2 or KFA6 series) play a critical role in ensuring intrinsic safety and signal integrity, especially in hazardous areas. These devices also enable reliable communication between the sensor and the control system. Explosion protection is crucial in industries such as chemical processing, oil and gas, and pharmaceuticals, and most devices in the table are certified for such environments. Power supply modules are also integrated into the system to energize sensors and convert their signals into standardized output formats. Overall, the combination of accurate sensors and appropriate interface units ensures reliable level monitoring, system safety, and efficient process automation.

In level measurement systems, various types of sensors are utilized, including vibro, conductometric, magnetic immersion probes, ultrasonic, hydrostatic, radar, and pulse-based devices. These sensors differ in terms of their output signals, such as NAMUR standard, 4...20 mA analog signals, or dry contact outputs. Their operation is supported by control and interface devices such as safety barriers, galvanic isolators, power supply modules, and signal converters, which ensure reliable signal transmission and functional integration into industrial automation systems. In hazardous areas with explosion risk, intrinsically safe systems based on the FISCO (Fieldbus Intrinsically Safe Concept) and Entity models are applied. These systems control cable inductance and capacitance within specified limits to prevent ignition sources. The sensors listed in the table are suitable for use in various industrial sectors, each certified and compliant with explosion-proof safety standards. Hydrostatic level measurement operates based on the pressure exerted by the liquid column within a tank or vessel. This method offers high accuracy and is less affected by external factors such as foam, sediment, or vapor. The measuring mechanism typically involves a stainless steel membrane that transmits pressure to a piezoresistive strain gauge sensor. The resulting signal is converted into an electric current proportional to the liquid level.

This current, usually within the standard 4–20 mA range, is transmitted to a control system for monitoring and processing. These advanced technologies enable real-time monitoring, ensure safe operation in hazardous environments, and enhance the reliability and efficiency of automated process control systems.

Modern level measurement technologies have undergone rapid advancement in recent years, driven by the growing demand for automation, precision, and safety in industrial processes. Various types of level sensors are used today, including ultrasonic, radar, laser-based, capacitive, conductive, magnetostrictive, vibrating fork, and hydrostatic sensors. Each technology has its advantages depending on application conditions such as the physical state of the medium (liquid, solid, slurry), tank geometry, temperature, pressure, and the presence of foam or vapors. Radar and ultrasonic sensors are increasingly used in non-contact applications due to their reliability and maintenance-free operation, especially in hazardous or corrosive environments. Guided wave radar (GWR) systems are gaining popularity for their high accuracy and ability to function in complex media, including multiphase conditions. Capacitive and conductive sensors are cost-effective solutions in simpler installations, while magnetostrictive sensors provide very high-resolution measurements, making them ideal for precision applications such as in the chemical and pharmaceutical industries. Hydrostatic pressure-based sensors remain one of the most widespread and dependable methods, especially in water treatment, food and beverage, and oil storage sectors. These sensors use piezoresistive or capacitive elements and offer excellent linearity and robustness.

Digitalization and Industry 4.0 have introduced intelligent level sensors equipped with microcontrollers and digital communication protocols such as HART, Modbus, and IO-Link. These smart sensors can transmit not only level data but also temperature, diagnostics, and predictive maintenance information to control systems. Wireless level sensors are also gaining momentum, especially in remote monitoring of tanks and reservoirs, minimizing wiring costs and installation time. Many sensors now come with explosion-proof and intrinsically safe certifications (ATEX, IECEx), making them suitable for use in oil & gas, chemical, and mining industries. Battery-powered sensors with low-energy communication protocols like LoRaWAN and NB-IoT are being deployed for smart city infrastructure and environmental monitoring.

As industries continue to adopt automation and smart manufacturing, the future of level measurement technologies lies in the integration with cloud-based monitoring systems, artificial intelligence for anomaly detection, and digital twins for real-time process simulation. The focus is shifting from isolated level sensing to full-scale asset management, where sensors serve as a bridge between the physical world and digital platforms. With continuous innovation, level sensors are becoming smaller, more energy-efficient, self-calibrating, and capable of adapting to complex process conditions, offering enhanced operational safety, process reliability, and cost efficiency.

Ultrasonic level measurement technology (UTT) is widely used for non-contact, continuous level monitoring of liquids and bulk solids. One of its key advantages lies in its ability to function effectively even in harsh environments, including those containing corrosive, adhesive, or sticky substances. This is possible because ultrasonic measurement is largely unaffected by the **chemical and physical properties of the medium**. However, the **speed of sound in air**, which is a crucial parameter for ultrasonic measurement, is influenced by various environmental factors—most notably **temperature, pressure, and humidity**. Table 8.5 demonstrates how the velocity of ultrasonic waves changes with temperature. For instance, sound travels at **343.8 m/s at 20°C**, and this velocity increases with rising temperature, reaching **377.5 m/s at 80°C**. Furthermore, **air pressure** also affects the speed of ultrasound: as atmospheric pressure increases, so does the speed of sound. This effect can lead to measurement deviations of up to **5% under normal atmospheric fluctuations**. While **relative humidity** also

influences ultrasonic velocity, its impact is typically smaller—around **2% difference** between dry and fully saturated air.

Table 1.3- Dependence of Ultrasonic Wave Propagation Speed on Air Temperature

Temperature, °C	Speed of Sound in Air (m/s)
-20	319.3
0	331.6
20	343.8
40	355.3
60	366.5
80	377.5

Ultrasonic level measurement technology (UTT) is a non-contact method that utilizes high-frequency sound waves to determine the level of a medium within a tank or reservoir. One of the major advantages of this method is that it is unaffected by the chemical and physical characteristics of the medium. As a result, it is highly effective for measuring levels of aggressive, abrasive, adhesive, and viscous substances. However, it is essential to consider that the speed of ultrasonic wave propagation is highly dependent on ambient temperature. Table 8.5 illustrates how the velocity of ultrasonic vibrations in the air increases as the temperature rises. At -20°C, the speed is approximately 319.3 m/s, while at 80°C, it reaches up to 377.5 m/s. This variation can influence the accuracy of distance or level measurement and must be compensated for in the sensor's electronics.

In addition to temperature, air pressure also affects the speed of ultrasonic waves. Higher pressure leads to a slight increase in sound speed—about a 5% variation in normal atmospheric conditions. Moreover, air composition, especially the percentage of carbon dioxide (CO₂) and humidity levels, also has an impact. However, the effect of humidity is relatively minor: the difference in ultrasonic speed between dry air and air saturated with moisture is only about 2%. The LUC4T type ultrasonic level sensor is one such example of modern UTT technology. It is designed with durability in mind and includes features that allow it to operate reliably even in the presence of internal tank constructions or mounting brackets.

In conclusion, advanced level measurement technologies are playing a critical role in the automation, optimization, and safety of modern industrial processes. The transition from mechanical and manual systems to intelligent, digital, and wireless sensors has significantly improved measurement accuracy, data integration, and real-time monitoring capabilities. Among various technologies, radar, ultrasonic, and guided wave radar systems stand out for their versatility, especially in hazardous or complex environments. Ultrasonic technologies offer the benefit of non-contact measurement but require temperature and pressure compensation due to air-dependent propagation speed. Meanwhile, radar-based systems remain robust under extreme conditions and are increasingly used across oil and gas, chemical, food, and water industries. The future of level measurement lies in smart sensors integrated with IoT platforms, enabling predictive maintenance, remote diagnostics, and cloud-based analytics. As industries embrace Industry 4.0, level sensors are becoming more compact, energy-efficient, adaptive, and capable of supporting digital twins. Continued innovation and standardization will further enhance their reliability and application potential. Ultimately, these technologies not only increase operational efficiency and reduce human error, but also contribute to environmental safety and sustainable industrial development.

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