Principles and Applications of Continuous Level Gauges in Level Monitoring of Solid Particles

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Abstract. In modern industries, such as electric power, medicine and food, the accurate measurement of continuous level for solid particles has played an important role in regulating the production schedule, ensuring the production automation, guaranteeing the production and personal safety. This article introduces the principles and characteristics of the level gauges usually used to measure the continuous level of solid particles at home and abroad, and analyzes the effects of different work conditions on the gauges. The unsuitable work conditions and the points for attention of installation and maintenance are summarized. In a word this article provides the theoretical basis and practical guidance for the accurate modal selection and correct use of the continuous level gauges for measuring the level of solid particles in different environments and industries.

1. Introduction
Continuous level gauges are widely applied and play important roles in monitoring the solid particles level of the automatic production in the fields of electric power, paper making, medicine and the like. On the one hand, accurate material consumption can be obtained, which is beneficial to regulating material balance and determining product output. On the other hand, the continuous and stable productions are ensured, and the accidents such as equipment damage and personal injury are avoided. This article introduces the principles and characteristics of various types of continuous level gauges for measuring the level of solid particles at home and abroad, and analyzes the applicability, installation and maintenance conditions of the gauges under complex and variable working conditions like temperature, dust concentration, adhesion, corrosivity, etc.

The sensitivity of the gauges under different working environments, the accuracy of measurement and the economy of application are summarized. This article provides technicians further insight into the differences and characteristics of the gauges and theoretical references for the model selection under different industries and working conditions, which gives technical guidances to ensure the accuracy of continuous level monitoring, the reliability of equipment and the safety of operators.
2. Principles and Applications of the Continuous Level Gauges

2.1. Capacitance Level Gauge

The principle of the capacitance level gauge is that the probe electrode (rod or cable type) and the solid particles or silo wall form a capacitor, whose value changes with the variation of the material level in the silo. The capacitance value is processed to be the voltage or current signals called the material level. The gauge can be applied to metal or nonmetal material silo, as shown in Fig. 1.

![Figure 1. Schematic diagram of capacitance level gauge.](image)

The gauge is prone to forming probe attachment, which leads to the change of capacitance value and inaccurate measurement of material level. When the gauge is installed, attentions should be paid to avoiding the feed inlet, shielding and grounding the signal wires. Probe attachment should be regularly checked. Meanwhile, the gauge should be completed verification.

2.2. Radio-Frequency and Admittance Level Gauge

The admittance value is generated between the probe of radio-frequency and admittance level gauge, silo wall and material. The change of material level causes the variation of admittance value and radio frequency signal. The signal change is converted into the output of analog signal to realize the continuous measurement of material level.

Level measurement technique by radio-frequency and admittance can measure impedance and capacitance respectively. The impedance and capacitance of the hanging material are equal. According to the equivalent circuit of the hanging material shown in Fig. 2, the influence of the hanging material can be eliminated by the technique. But in the equivalent circuit, the impedance of the hanging material consumes energy, which leads to the voltage drop of the oscillator, output change and measurement error. Therefore, it is necessary to replenish the consumed energy in order to eliminate the measurement error. It cannot be installed where material flows directly.
2.3. Heavy Hammer Level Gauge
The motor in the probe unit of the heavy hammer level gauge is rotated and the heavy hammer with the wire rope is lowered. As shown in Fig. 3, when the heavy hammer falls to the material level, the wire rope is relaxed and the micro switch contacts. Then the controller calculates the height of the material level. Moreover, the motor reverses, causing the heavy hammer back. A period of material level detection is completed.

In the process of measurement, various problems exist. The hammer drops because it is adhered, scoured and impacted by the material. The mechanical fatigue causes the wire rope to break. The mechanical blocking is due to the material with corrosive or cohesive property. The electrical device is polluted by the dust. Therefore, in order to reduce the probability of dropping and burying hammer, it is necessary to avoid detecting the material level during the loading process, and check regularly to eliminate mechanical faults. The gauge must be kept straight down and avoided the feed inlet when installed.
2.4. Weighing Level Gauge

The weighing level gauge uses the weighing sensor (see Fig. 4) to measure the weight of the material together with the silo. The measurement result subtracts the weight of the silo. Then the material level is calculated according to the datas of material density and silo size.

![Figure 4. Schematic diagram of weighing level gauge.](image)

Due to the elastic connection between the silo and weighing sensor, it is necessary to design the installation mode and position of the sensor specially. The design and installation costs are high. The stability of the installation structure is poor, so strong wind, earthquake, agitation or vibration may lead to the collapse of the silo. The material containing moisture, material stacking surface being not plane, the phenomenons of rat hole, bridge, and collapse in the silo could cause the measurement error. It should verify that all the sensors are installed at the same height and calibrate all the sensors after installation.

2.5. Patch level gauge

In the process of charging and unloading, the support structure of silo produces elastic deformation which is proportional to the material weight in a certain range. This principle is precisely applied in the patch level meter. According to Fig. 5, the gauge is fixed on the support structure, and the deformation is detected, which is converted into electric signal. Therefore the material level is calculated. The influence factors such as rat hole, bridge building, collapse, stacking shape and fluidity are avoided with the gauge. The measuring curve is smooth.

![Figure 5. Diagram of patch level gauge.](image)
The installation of the gauge does not require complicated modification like opening and welding for the silo body, which reduces the difficulty of design and installation, and does not affect the production activity. The material absorbs moisture, dust adhered to the gauge can change the resistance of strain gauge. All these make the wrong results, so the gauge needs to be calibrated and cleaned up frequently.

2.6. Ultrasonic Level Gauge
According to the principle of echo ranging, the ultrasonic level gauge (see Fig. 6) emits the ultrasonic wave, which is reflected from the material surface and received. Then the time span of the ultrasonic transmission is calculated. Because the time span to receive the echo is proportional to the distance from the probe to the material surface, the material level is converted.

The material is loosely stacked. The surface roughness is large. So the ultrasonic wave is scattered and the echo energy is attenuated. The high concentration of dust or steam in the silo causes the ultrasonic wave to be reflected and the false echo signal to be produced. All these factors can affect the measurement results. In addition, volatile substances and dust attached to the probe can also affect the emission and reception of the ultrasonic. Therefore, the probe needs to be often cleaned. The installing demands evading the blind areas.

![Figure 6. Schematic diagram of ultrasonic level gauge.](image)

2.7. Radar Level Gauge
The principle of the radar level gauge is the same as the ultrasonic level gauge, except that it emits the radar wave, as shown in Fig. 7. Radar waves do not require transmission media and are not affected by interference sources such as temperature, steam and dust.

![Figure 7. Schematic of radar level gauge.](image)
The shape of radar antenna determines the focusing capability, sensitivity of radar wave and the suitable applicability of the gauge. The bar antenna is suitable for corrosive materials and often used to measure the level of silo with large diameter and small measurement range. The horn antenna has good focusing capability, but is disagree with corrosive materials. The parabolic antenna is good for rounding obstacle and measuring small range targets due to small emission angles. The casing antenna should be selected when the dielectric constant of the material is small or the environment in the silo is easy to cause false reflection, but it is required that the material has no adhesiveness to the antenna. Guided wave radar is not affected by dust and steam. However, it is also required that the material has no adhesiveness to the antenna and the appropriate model should be selected according to the dielectric constant of the material. When the gauge is installed, the main axis of radar wave channel should avoid obstacles such as beam, feed inlet, mixer and so on.

2.8. Laser Level Gauge

The measurement principle of the laser level gauge (see Fig. 8) is the same as that of the radar level meter, but the gauge emits a kind of continuous or high speed pulse laser beam. Because Laser has good monochromaticity, coherence and directivity, the the gauge is not affected by the material dust, reflection coefficient, dielectric constant, temperature and so on.

![Figure 8. Schematic diagram of laser level gauge.](image_url)

The gauge is suitable for the occasions with bad environment, fast change of material level, narrow space and high measuring precision. To eliminate the measuring error, it is necessary to prevent the gauge from being interfered by the same band light source and the deep color material absorbing the laser. The probe of the sensor should be installed parallelly to the silo wall.

2.9. Passive Nuclear Level Gauge

The gamma ray and X ray released from the natural radioactive nuclear element in the material are shown in Fig. 9. When the material level changes, the intensities of the rays detected by the detector are different. Signal recognition and processing technologies are used to extract the material level signals to judge the location of the material.

The gauge has no radioactive source itself, which eliminates the nuclear radiation hazard. It is not limited by the fact that the gauge cannot be installed at the top, the measuring environment is poor and the dust is easily attach to the gauge. The passive nuclear gauge cannot be applied when the silo wall is cement and other similar materials, because this kind of material is the background radiation source measured, which will interfere with the monitoring of the material position, and cause the misreport of the material position. The passive nuclear gauge is installed directly outside the silo without opening.
2.10. Active Nuclear Level Gauge

The active nuclear level gauge is composed of radioactive sources, detectors, etc. (see Fig. 10), using man-made sources to emit radiation. The radiation is blocked and absorbed by materials, and the radiation intensity is changed. The detector determines the material level according to the change of the radiation intensity.

The gauge is suitable for the level measurement under the poor environment such as high temperature, strong corrosiveness, and heavy dust and so on. The gauge has the disadvantages like attenuation, pollution, damage to human body by radiation source. The use of radiation source must follow the three protection principles of ‘time, distance and shielding’. A professional should be responsible for keeping, switching and maintaining the radioactive source.

3. The Characteristics and Applications of Continuous Level Gauges

As shown in Table 1, the applicabilities of various level gauges under different environments are introduced, such as temperature, dust, adhesion and so on. The accuracies, economies, installations and maintenances of the measurements of the gauges are summarized.
Table 1. The characteristics and applications of continuous level gauges.

| Gauge Type Working condition | Capacitance /Radio-Frequency and admittance | Heavy hammer | Weighing | Patch | Ultrasonic /Radar | Laser | Passive nuclear | Active nuclear |
|-----------------------------|--------------------------------------------|--------------|----------|-------|-------------------|-------|----------------|----------------|
| Temperature                 | Influence                                  | Not influence| Not influence| Not influence | Not influence | Not influence | Not influence | Not influence |
| Steam                       | Not influence                              | Not influence| Not influence| Not influence | Influence ultrasonic wave propagation | Not influence | Not influence | Not influence |
| Dust                        | Make material level misinformation          | Not influence| Not influence| Not influence | Produce false signals | Not influence | Not influence | Not influence |
| Corrosion                   | Damage probe                               | Corrode cable and hammer head | Not influence | Not influence | Corrode detection unit | Corrode launcher | Not influence | Not influence |
| Adhesion                    | Cause probe attachment                      | Cause material adhesion | Not influence | Change resistance for strain gauge | Cause probe attachment | Not influence | Not influence | Not influence |
| Accumulation form of material | Influence                               | Influence | Influence | Influence | Influence | Influence | Influence | Influence |
| Rat hole, bridge, wall, etc. | Not influence                              | Not influence| Not influence| Not influence | Cause false measurement | Not influence | Not influence | Not influence |
| Permittivity                | Change capacitance                         | Not influence| Not influence| Not influence | Absorb electromagnetic waves | Not influence | Not influence | Not influence |
| Electromagnetic wave noise  | Need shielding and filtering                | Not influence| Not influence| Need shielding and filtering | Need Signal processing | Not influence | Not influence | Not influence |
| Precision                   | Disturbed easily                           | Accurate     | Disturbed by the material moisture | Disturbed by the material moisture | Accurate | More accurate | More accurate | More accurate |
| Installation                | Installed on top, Avoid obstacles           | Installed on top, Avoid obstacles | Require specially design installation method | Fixed to metal support structure | Installed on top, Avoid obstacles | Installed on top, Avoid obstacles | Installed outside of silo | Installed by professional |
| Maintenance                 | Clean up hanging material                   | Remove mechanical faults | Require Calibration | Clean up probe / antenna | Clean launcher | Checkup detector | Checked by professional |
| Economy                     | More cheap                                | Cheap        | More cheap | More cheap | Cheap | Costly        | More costly | More costly |

4. Summary
The capacitance level gauge is easily affected by the probe attachment. The heavy hammer level gauge is easy to generate mechanical fault. The precision of the weighing level gauge is not high. The patch
level gauge requires the metal support structure of silo. The ultrasonic level gauge is affected by the dust and steam obviously. The passive nuclear level gauge cannot be used on the silo whose silo wall is the radiation source. The radio-frequency and admittance, radar, laser and active nuclear level gauges have better versatility under different working conditions, but the laser and active nuclear level gauges are expensive.

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