Hot Cathode Ionization Gauge "G-TRAN series ST2" Obtained High Stability and Long Life[*1]

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Because of changes in the operating environment and the material processing with the vacuum equipment, lowering and fluctuation of the reading value of the ionization vacuum gauge has increased. Therefore, we focused on the triode ionization vacuum gauge that has a feature of high stability and high accuracy, we developed the world's first small metal type gauge head of triode ionization vacuum gauge. In environments such as oil is deposited, it was confirmed that a long period of time the reading value is more stable than the cold cathode ionization vacuum gauge and B-A ionization vacuum gauge.This triode ionization vacuum gauge that we have developed is an old technology, but we believe can contribute to solution in the new market.

1. Introduction

Hot cathode ionization vacuum gauges used for measuring pressure in a high vacuum range have been causing a growing number of problems in recent years. Hot cathode ionization vacuum gauges exhibit low or fluctuating readings, and cold cathode ionization vacuum gauges often fail to discharge electricity. Users, noticing low or fluctuating readings, are likely to think that the problem is caused by life time and replace it. These problems are attested by the "Report on the Results of Questionnaire about Role of Vacuum Gauges and Vacuum Standard"[1)], which says that more and more users are calling for accurate and stable vacuum gauges. This paper reports on the development of an ionization vacuum gauge with a gauge head that has improved stability and that satisfies the demand for accurate and stable vacuum gauges.

2. Problems with the cold cathode ionization vacuum gauge and the B-A ionization vacuum gauge

A metal material, such as stainless steel, is used for manufacturing the vacuum chambers of vacuum equipment. The type of cutting fluid used for processing this metal material has recently been changed from cutting oil to a water-soluble type due to the demand to reduce environmental loads. Since the end of 1995, when the production of CFC, an ozone-depleting substance, was abolished, fluorocarbon-based cleaning agents used for cleaning processed materials have been changed to environmental load-reducing water-based or hydrocarbon-based cleaning agents. It was from that time that cutting fluid and cleaning agent residue started to be observed inside chambers.

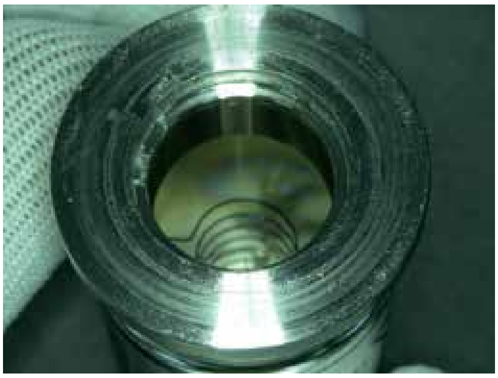

Figure 1 Connection flange coated with vacuum grease.

Immediately after the vacuum equipment starts operation, the residue generates gas, which often lowers the readings of cold cathode ionization vacuum gauges and a B-A ionization vacuum gauges. Also, there are cases in which applying vacuum grease on the O-ring of a gauge-head connecting flange as shown in Figure 1, and using an O-ring made of nitrile rubber instead of fluororubber resulted in lowering readings. In addition, many recent devices manufactured through vacuum processes use new materials such as films, acrylic substrates, and organic EL materials. These materials also generate gas that lead to lowered readings.

As the cold cathode ionization vacuum gauge utilizes electric discharge to provide an pumping effect larger than that of the hot cathode ionization vacuum gauge, organic materials tend to be deposited on its electrode in the environment described earlier. This can cause unstable discharge leading to unstable readings and, eventually, discharge extinction[2)]. An oil diffusion pump was modified by removing a baffle to let oil climb the pipe, and an electrode was operated just above this pump. Figure 2(a) is a photograph of this electrode. It shows carbide sticking to the electrode surface. If a pressure to be measured is near the upper measurable limit, readings become unstable

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(a) (b)

Figure 2 (a) Electrode of cold cathode ionization vacuum gauge when mounted and used directly above oil diffusion pump. (b) Electrode of cold cathode ionization vacuum gauge when argon gas was introduced up to about 1 Pa and operated continuously.

and the time until the discharge stops becomes extremely short, which are caused not only by these organic materials but also by the cathode being sputtered. Figure 2(b) is a photograph of an electrode that was operated continuously with argon gas introduced up to approx. 1 Pa. It shows some sputtered cathode material stuck to the surface.

Most hot cathode ionization vacuum gauges that are currently used are B-A ionization vacuum gauges. The B-A ionization vacuum gauge collects ions using an electrode called an ion collector that is made of thin metal wires. When organic substances present in the atmosphere to be measured attach to the ion collector, they start to deposit on it because they have large activation energy for desorption and a long average residence time. Deposited organic substances form an insulator that cannot collect ions, which lowers readings[3]. Figure 3 is a photograph of an ion collector that was used in a vacuum dryer. It shows carbide emitted from a workpiece to be dried sticking to the ion collector.

A combination vacuum gauge that incorporates other gauges such as a Pirani vacuum gauge has become available on the market. This gauge continuously measures

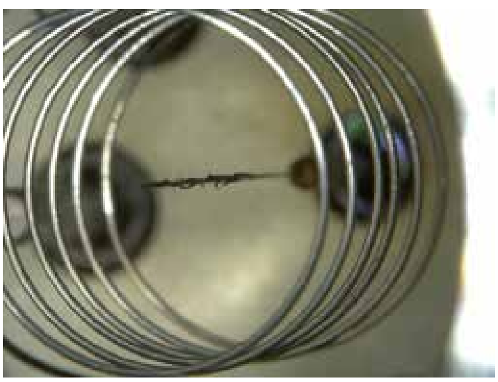

Figure 3 Ion collector of B-A ionization vacuum gauge whose indicated value is lowered.

pressure covering a much broader pressure range than ever before. This combination vacuum gauge automatically controls the filament and its high voltage using values indicated by the Pirani vacuum gauge (or whatever kind of gauge is being used), and continues operation even when the pressure is close to the upper measurable limit, which causes even more contamination of the electrode .

If readings are lowered, the equipment needs to be stopped and its chamber needs to be exposed to the atmosphere so that the gauge head can be replaced. This reduces productivity. In addition, used gauge heads are disposed of even though they contain rare metals such as tungsten, molybdenum, iridium, and platinum. More and more of these rare metals are used for electronic devices every year. Mining and smelting these materials can cause serious environmental pollution such as water and soil contamination. Rare metal prices are unstable because their mines are located in specific regions. Therefore, an increase in the frequency of replacing gauge heads not only causes a decrease in equipment productivity and increase in maintenance cost, but also damage to the environment. Also, because of the structure of these combination vacuum gauges, some normally functioning parts also need to be replaced, which is another cause of increased maintenance costs.

3. Design of a new hot cathode ionization vacuum gauge

In the midst of this situation, the authors developed a vacuum gauge that allows multiple gauge heads with different measurement ranges to be connected[4]. However, the gauge head stability and the replacement frequency did not improve. In order to solve the problems mentioned in the preceding section, the authors then focused on the triode ionization vacuum gauge, which is more stable in sensitivity and more accurate than the cold cathode ionization vacuum gauge and the B-A ionization vacuum gauge. The triode ionization vacuum gauge is one of several types of hot cathode ionization vacuum gauges.

The triode ionization vacuum gauge used to be used as a secondary standard ionization vacuum gauge (VS-1)[5], because it features stable sensitivity and little variation among gauge heads due to the rotational symmetry of its electrode. Moreover, although its sensitivity is about the same as that of the B-A ionization vacuum gauge, deposition of organic substances has little impact on its sensitivity[3] because its ion collector area is several thousand

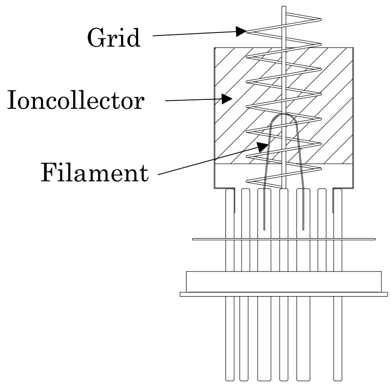

Figure 4　Structure of gauge head.

Figure 5　Buffle.

Figure 6　Sensor unit, gauge head (left) and display (right).

times larger than that of the B-A ionization vacuum gauge. However, use of the triode ionization vacuum gauge gradually declined because a soft X-ray effect restricts its lower measurement limit to about 1×10^{-5} Pa, which means it has a measurement range smaller than that of the B-A ionization vacuum gauge. Eventually, only an old large type with a glass vacuum tube was available on the market. To decrease the installation space and prevent fracture, the authors then developed a small metal-tube-type gauge head (Figure 4). Although a filament support electrode supported the hairpin-shaped filament top in the old glass tube type, the new design eliminated the filament support electrode to make the gauge smaller, and shortened the filament in order to reduce deformation due to the long heating time and the self-weight. As the temperature at the top is highest which increases the emission of thermoelectrons when powered on, the design positioned the filament top at the center of the grid to curb the filament power consumption and improve the sensitivity[6]. The design of the filament material employed yttria-coated iridium, which is resistant to oxidation and allows operation at lower temperatures than with tungsten.

Using a shorter filament, lower heating power, and an yttria-coated iridium filament decreased the radiant heat from the filament and made the temperature of the ion collector lower than that of the old glass tube type with a tungsten filament. When the temperature of an ion collector is low, it becomes dirty quickly. To increase the ion collector temperature as much as possible, the new design improved two items. First, the ion collector surface area was reduced to the minimum in the range that does not affect its sensitivity, which reduced its heat capacity[7]. For conventional triode ionization vacuum gauges, the length of the ion collector in the generating line direction is the same as that of the grid or larger. However, most ions hit the filament top area, which is the central area of the ion collector, and fewer ions hit the areas closer to the ends. For this reason, the new design cut off the areas around both ends. The smaller area of the ion collector also reduced the amount of dirt that was absorbed by the ion collector. Secondly, the emission current at 1×10^{-2} Pa was designed to be 2 mA, which is larger than that of a B-A ionization vacuum gauge of the same size[8]. To increase the emission current, one needs to increase the current that passes through the filament. This also increases the heat radiation of the ion collector.

The standard connecting flange of the gauge head is equipped with a metal mesh. An optional baffle (Figure 5) is available to protect the filament, the grid, and the ion collector for times when there is a possibility that foreign objects could fly into the gauge head.

The gauge head directly connects to the control section, to which a Pirani gauge and an atmospheric pressure sensor can also be connected. Also, a display unit that indicates readings can be connected (Figure 6). When continuously measuring pressures close to the upper measurable limit with a Pirani gauge connected, the filament of the ionization vacuum gauge can be turned on or off from the outside so that the filament does not get dirty easily.

As an yttria-coated iridium filament is used, it gradually requires more power to obtain the specified emission cur-

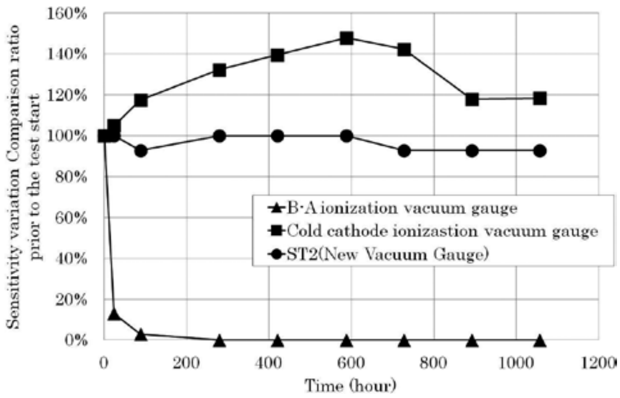

Figure 7 Stability test in case of being installed directly above the oil diffusion pump.

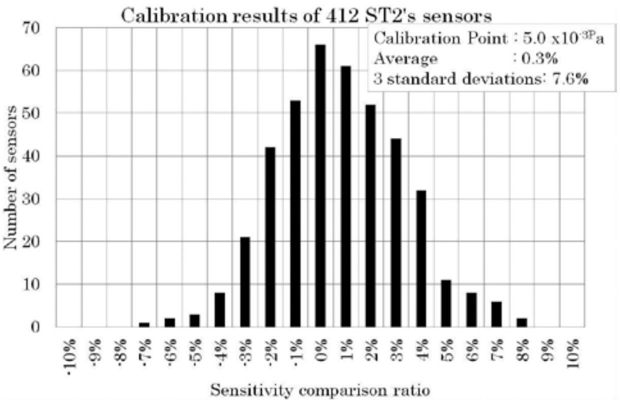

Figure 8 Sensitivity distribution of new developed gauge.

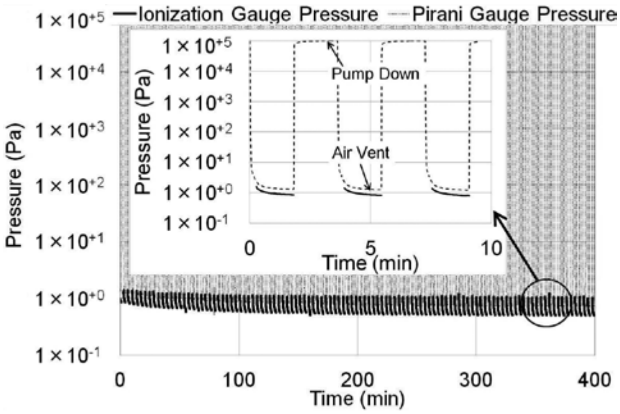

Figure 9 Vacuum breaking test.

rent, and it eventually becomes unable to turn on when the power exceeds the capacity of the control circuit. This device measures the current of the filament, and then outputs a signal before the filament becomes unusable to indicate when to replace the gauge head. The gauge head can be replaced by itself. It does not require checking the condition of the inside of the gauge head like a cold cathode ionization vacuum gauge does, nor does it require cumbersome disassembly/assembly with special tools.

4. Performance of the new hot cathode ionization vacuum gauge

The newly developed vacuum gauge, cold cathode ionization vacuum gauge (inverted magnetron type), and small metal-tube-type B-A ionization vacuum gauge were mounted directly on a diffusion pump that was modified to let oil climb the pipe by removing the baffle. Figure 7 shows the results of checking the stability of each gauge reading with this setting. The vertical axis represents a ratio with the reading at the beginning of measurement being 100%. The B-A ionization vacuum gauge showed readings that dropped immediately after starting measurement and reached 13% in 24 hours. The readings of the cold cathode ionization vacuum gauge changed greatly immediately after starting operation and rose to 148% in 588 hours. In contrast, the readings of the newly developed vacuum gauge stayed between 90 and 100% for over 1000 hours. In other words, the newly developed vacuum gauge is much more stable in an environment where a gauge head absorbs dirt than the cold cathode ionization vacuum gauge and the B-A ionization vacuum gauge. For this reason, it can operate for a long time eliminating the need to replace the gauge head to gain a longer lifetime.

At 1×10^{-1} Pa or higher, the ion current included in the emission current cannot be ignored, and the sensitivity changes due to the space charge effect of electrons and ions and thermal transpiration[5]. Software compensated for these changes to maintain the measurement range at 1×10^{-5} to 10 Pa. As the variation of readings due to differences in gauge heads is within ±8% as shown in Figure 8, the measurement accuracy was specified as ±10% for the range of 1×10^{-4} to 3 Pa. In measuring a pressure of 1×10^{-4} Pa or lower that is close to the lower measurable limit (equivalent to a pressure represented by a residual current), special care such as substantial baking is required[9] because an extremely small amount of gas that is hard to remove escapes from the gauge head, pipes, and O-rings.

As hot cathode ionization vacuum gauges use a filament, they do not need a long time until measurement can be started while cold cathode ionization vacuum gauges do. Although some users may think filaments are prone to burnout, gauge head filaments are robust enough today because most products on the market use an yttria-coated iridium filament, and a control circuit protects it from sudden exposure to the atmosphere. Most abnormally functioning B-A ionization vacuum gauges show low readings.

Table 1 Specification list.

Name	Multi-ionization gauge ST2
Connectable gauge head	ST2 gauge head SWT-16 (NW16), SWT-25(NW25) : 1 SPU Pirani vacuum gauge measuring unit: 1 (option) SAU pressure sensor unit: 1 (option)
Measurement pressure range (N_2)	ST2 independent mode: 1×10^{-5} Pa to $1\times10^{+1}$ Pa
Accuracy (N_2)	ST2 independent mode: 1×10^{-4} Pa to $3\times10^{+0}$ Pa: ±10%
Repeatability (N_2)	ST2 independent mode: 1×10^{-4} Pa to $3\times10^{+0}$ Pa: ±2%
Measurement gas type	Indicates pressure as sensitivity for N_2
Emission current	2 mA (1×10^{-2} Pa or lower), 10 uA
DEGAS	Electron bombardment - Emission current 2 mA, grid voltage approx. 330 V
Gauge head material	Filament: Ir/Y_2O_3-coated Others : PtC-Mo, SUS304, W, Kovar glass, Kovar/Ni plating
Gauge head withstand pressure	SWT-16: $2\times10^{+5}$ Pa (absolute pressure) * Take the withstand pressure for flanges, clamps, and other components into account separately.
Gauge head internal volume	SWT-16: 17 cm^3, SWT-25: 19cm^3
Operating temperature range	10 to 50℃
Bake out temperature	Sensor head : 150℃ (when controller is disconnected)
Power supply voltage	20 to 28 VDC (ripple, noise 1% or lower) 19 W or lower (156 W when power supply turned on)
Sensor weight	Controller: Approx. 530 g, SWT-16: 80 g, SWT-25: 80g
External dimensions	144×75×62 mm (approximate, controller section)

The newly developed hot cathode ionization vacuum gauge and Pirani vacuum gauge were installed in a vacuum chamber, and the operation cycle shown below was carried out repeatedly. Figure 9 shows the test results.

(1) Perform evacuation. (Pump Down in Figure 9)

(2) When the Pirani vacuum gauge indicates 4 Pa, turn on the filament of the hot cathode ionization vacuum gauge.

(3) When the Pirani vacuum gauge indicates 1 Pa, perform vacuum break. (Air Vent in Figure 9)

Performing vacuum brake 100 times or more did not break the filament of the newly developed hot cathode ionization vacuum gauge. However, note that an atmosphere of halogen gas that reacts with the filament prevents emission of thermoelectrons from the filament, which disrupts the measuring operation.

Table 1 shows the main specifications. A JCSS calibration option that extended the calibration range from 1×10^{-4} Pa to 133 kPa became available in 2014.

5. Conclusion

This report described a one-of-a-kind small metal-tube-type triode ionization vacuum gauge that reduced the gauge head replacement frequency even if used in a severe environment compared with B-A ionization vacuum gauges and cold cathode ionization vacuum gauges. In order to convey the advantages of high stability and long lifetime that are not included in the product specification, the authors created and distributed leaflets containing cartoons and animations. The authors also made a piece of equipment with a glass pipe attached to an exhaust system that is made by modifying a diffusion pump so that oil absorbed on the pipe and gauge head can be easily observed. At some exhibitions, this equipment let visitors actually witness the stability of the readings. Furthermore, the following systems have been lent out for evaluation: bulb evacuation equipment, vacuum heat treatment furnaces, vacuum degassing furnaces, vacuum dryers, sputtering equipment, ion-plating equipment, and vacuum deposition equipment. This lending service is going on now. Users are recommended to contact the closest sales office.

There is no single perfect vacuum gauge unit that applies to all purposes and applications at the same time[10]. We will continue to exchange information on the characteristics and purposes of vacuum gauges with customers, and will provide solutions to problems arising in the new market of vacuum gauges by making use of triode type gauges that use an old technology.

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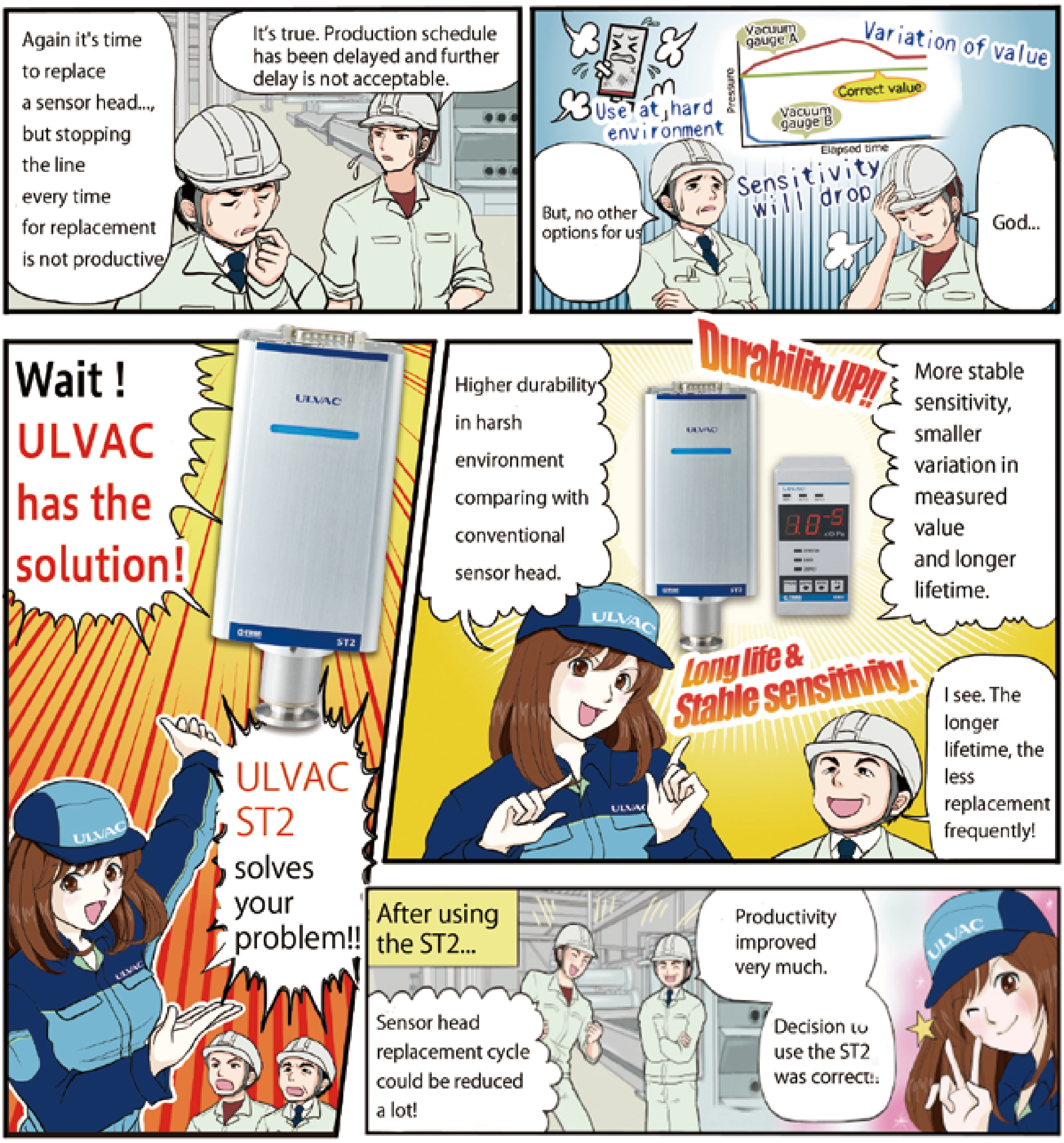

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