PFEIFFER VACUUM

BRINGING ELECTRICITY TO MILLIONS

Vacuum in the manufacture of transformers, isolators and high-voltage switchgear

Power transformers are needed to transfer energy from power plants or public electricity networks to the consumer. They regulate electricity voltages and flows upwards and downwards to transfer energy cost-efficiently and to provide the necessary voltages. In the manufacture of these transformers, vacuum technology is required at various stages of the production process:

for drying windings, for degassing transformer insulating oil and for evacuating the transformer tank and expansion vessel before and during the oil filling process.

Drying windings

The aim of the drying windings is to remove water, tannic acid and acetic acid from paper and wood and to remove polymers as well as wax from the paper insulation. In high-performance transformers, the potential for flashovers dictates that the residual moisture content must not exceed 0.1 – 0.3 percent. This is to prevent the occurence of flashovers. As a result, electrical losses are reduced to a minimum and the insulation resistance is improved. In the vacuum range of 0.1 – 10^{-2} hPa, the insulation resistance is at an ideal level for the actual application. The vacuum required for drying the windings is generated with a combination of Roots pumps and rotary vane pumps. If the application is a clean one, dry pumps are used as backing pumps for the Roots pumps. There are different principles available for drying the windings. The most effective procedure is vapor phase drying (VPD).

Production stage	Process	Required vacuum
Drying windings	**Vapor drying**	< 10^{-2} hPa
Conditioning of tank and condensation chamber before and during filling with insulating oil	**Removal of humidity (water) and contaminants through condensation**	5 10^{-2} – 10^{-3} hPa
Degassing of insulating oil	**Removal of humidity/contaminants in oil through condensation**	< 0.5 hPa

Table 1: Vacuum drying processes in transformer production

Vapor phase drying (VPD)
Pfeiffer Vacuum developed this drying process in the 1960s. Even today, it is still the most effective method for drying windings.

Vapor phase drying makes use of the thermal conductivity of the kerosene or alcohol sprayed into the drying chamber as well as of the uniform heating of the insulation material. The kerosene that is injected has similar chemical properties to the insulating oil. Since the process occurs under vacuum, the depolymerization factor is considerably reduced. This significantly extends the life of the insulating material.

Kerosene has a particular surface tension of its own. In addition to this, it can penetrate into even the finest cracks due to its extremely low density. In view of these properties, the drying process is 50 - 60 percent faster than drying with other methods, such as hot air. With vapor phase drying, windings dry within a matter of days, but certainly within a week at most. This fact increases output and optimizes costs by boosting the effectiveness.

What happens in vapor phase drying?

1. Depending on their size, either the whole transformer or just the paper-insulated copper windings are slid into the drying chamber on a rail system. Today, drying chambers are constructed with a volume of up to 1,000 m^3.
2. To accelerate the dehumidification process, the drying chamber is heated to a temperature of about 105° to 110°C.
3. The required insulation temperature is attained when the temperature in the chamber is at least 105°C.
4. Kerosene has already been injected by the JET vaporizer and heated up with the heating module. The vacuum/condenser module now removes the kerosene bit by bit through steadily lowering the pressure to approximately 20 hPa.
5. All connections to the vaporizer and condenser module are then closed.
6. The vacuum pumping station is switched on to start the fine evacuation process. The process is ended once vacuum conditions of <10^{-2} hPa are obtained.
7. The residual moisture content must not exceed 0.3 percent. For high-end transformers, this figure is 0.1 percent. The actual residual moisture is determined accurately at the vacuum pump exhaust using dew point measuring equipment.
8. The tank is filled with degassed insulating oil under vacuum conditions. An overflow protection device is essential here to protect the vacuum pumps from hydraulic lock. Only this protection can prevent the insulating oil from ingressing into the vacuum pumps while they are running. Roots pumps in particular are protected from potential destruction as a result.
9. The kerosene is reprocessed in a distillation module during the medium vacuum process and stored in a separate collecting tank for further use.

Evacuating the transformer tank
No moisture, such as water or contaminants resulting from condensation, is allowed to be present during the manufacture of transformers. So it is important that this moisture is thoroughly removed. Therefore, mobile vacuum systems are needed which are precisely tailored to the particular application. When evacuating transformer tanks, precisely defined standards must be taken into account: as an example, the evacuation port on the transformer tank has a standard size of 80 millimeters. This relatively small opening results in significant conductivity losses where < 1 hPa. Consequently, the pumping speed of the vacuum pumping station is considerably reduced. At the same time, this standard also adversely affects the pump-down time: It takes much longer and thus lowers the production output in turn. The use of larger vacuum pumps does not result in any improvement either – it merely increases the production costs.

In view of the restriction in the nominal diameter, the mobile vacuum unit needs to be attached as close as possible to the 80 millimeter opening. The use of short vacuum intake hoses can limit conductivity losses in this way. Normally, these hoses are four to five meters long.

Determining the residual moisture
The residual moisture can be measured using dew point measuring devices at the vacuum unit exhaust or vacuum gauges. Only capacitive gauges should be used for vacuum measurements. These are highly accurate and corrosion-resistant, and measurements do not depend on the type of gas used. The residual moisture reading is merely an indication based on the vacuum. It is therefore important that the vacuum measuring device is extremely accurate. Only this will ensure that the residual moisture does not exceed the prescribed limit. Inexpensive Pirani vacuum gauges obtain an accuracy of only +/- 15% and > 1 hPa in the low measurement ranges, the deviation can amount to 30 percent or more.

Reprocessing the insulating oil
Also the insulation oil must be free of all moisture and contamination to prevent internal flashovers from occurring. A precise oil purity to be maintained is defined for this purpose. This purity is achieved by subjecting the insulating oil to a degassing process.

During this degassing process, moisture, air and other contaminants are removed from the insulating oil before it is filled into the transformer. Therefore, vacuum conditions of < 1 hPa are necessary. Three-stage Roots or rotary vane pumping stations (pumping speeds: 1000/500 m^3/h for Roots pumps; 100 – 200 m^3/h for single-stage rotary vane pumps) or two-stage rotary vane pumps with a pumping speed of 250 m^3/h and an intermediate condenser are used for this purpose.

High-voltage switchgear and isolators
Sulfur hexafluoride (SF_6) – an odorless, inert and uncritical gas – is used as an insulating gas in medium-voltage and high-voltage switchgear and systems (GIS) as well as in gas-insulated pipes (GIP) for fully encapsulated systems in the voltage range of 5 to 1000 kV. In addition, the gas is also used for discharging the arc when switching high-voltage switchgear.

The arc interruption properties of sulfur hexafluoride are three times higher than those of air and nitrogen. In view of these properties and its low dielectric losses, SF_6 is ideal for the specific uses named. To maintain the insulating properties, the gas is at a pressure of 5 to 10 bar. This elevated pressure reduces the mean free path of the electrons. The purpose of this reduction is to prevent electrons from accelerating too hard and colliding prematurely with the SF_6 molecules.

Fig. 1: Pfeiffer Vacuum drying pumping station

High-voltage switchgear that is to be filled with SF_6 insulating gas must also be dried beforehand in vacuum chambers. Just as for transformer processes, vacuum conditions of <10^{-2}hPa are needed for these drying and filling processes.

On-site maintenance in field use
Regular maintenance is essential for ensuring the good working order and safe operation of transformers, high-voltage switchgear and isolators. Gradual ingress of moisture through any existing leaks can cause internal flashovers to occur.

INFO BOX

Conductivity losses affect pumping station performance

- The pumping speed of a three-stage pumping station that is directly attached to the drying chamber is shown by the blue line of the graph. This configuration does not translate well into practical use, however
- The influence of the 80 millimeter inlet port on the pumping speed of the three-stage pumping station is shown by the red line on the graph. If vacuum conditions of 5 10^{-3} prevail, the pumping speed is only 80 m^3/h where a capacity of 3,200 m^3/h is installed
- The difference in pumping speed is due to conductivity losses resulting from the small nominal diameter of the intake pipe in the pressure range < 1 hPa
- A marked improvement in the pumping speed as well as the reduction of the pump-down time could be achieved through changing the standard to a nominal diameter such as 100 millimeters.

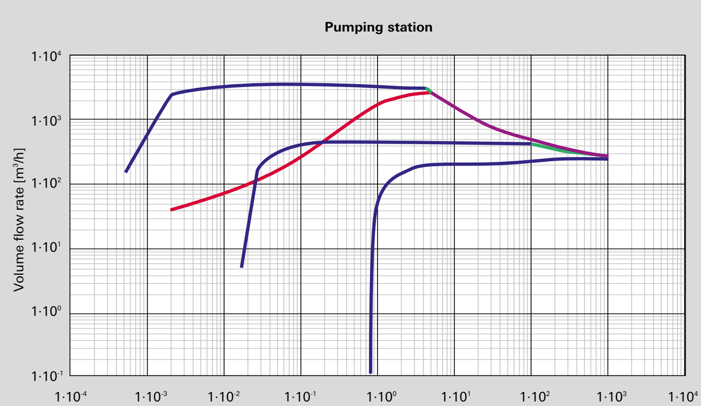

Table 2: Influence of conductivity losses on pumping station performance

Fig. 2: Pfeiffer Vacuum DuoLine rotary vane pumps cover the pumping speed range of 1.25 to 1,920 m^3/h

A defined maintenance schedule specifies when tanks must be emptied and tested for leaks and then be refilled with insulating oil or SF_6 gas.

The vacuum pumps and filling equipment are placed on trucks for performing on-site maintenance. Power is supplied by diesel generators.

Leak testing for quality assurance
Leak testing is essential for quality assurance, whether during production or on-site maintenance.
The pressure rise method is only suitable for detecting large leaks with a leakage rate of 10^{-1} hPa m^3/s. If higher leak tightness is required, then helium leak detectors must be used. They measure leaks accurately and reliably. Mobile and portable leak detectors weighing up to 25 kilograms come into their own in transformer production, since these can also be used in the field.

Rotary vane or dry pump as a backing pump?
Dry pumps are becoming increasingly popular. But when it comes to applications such as vapor phase transformer drying or drying windings, rotary vane pumps are ideal due to their technical properties. The oil operating temperature in rotary vane pumps with an opened gas ballast valve is 80–85°C. Dry pumps, in comparison, reach gas temperatures of between 150° and 180°C due to the heat build-up through internal compression.

If polymers and wax occur during the vapor drying process, they burn on the hot rotors when dry pumps are used. This leaves a black coating that prevents pumps from starting up again after they have been switched off and necessitates a full clean.

If rotary vane pumps are used, however, the polymers and liquid wax remain in the oil and are drained away when the oil is changed. This allows the pump to be filled up again with fresh oil and be re-used immediately. The matter of disposing of the oil is therefore the only measure which has to be taken into account.

Fig. 3: Pfeiffer Vacuum OktaLine Roots pumps with a magnetic coupling

Fig. 4: CombiLine Roots pumping station from Pfeiffer Vacuum

Fig. 5: Portable leak detector ASM 310 from Pfeiffer Vacuum

Pfeiffer Vacuum solutions
Pfeiffer Vacuum has the right solution both for generating the necessary vacuum conditions and for conducting leak testing with mobile leak detectors. The extensive portfolio contains the following solutions that are suitable for transformer and high-voltage switchgear production processes:

- Single-stage and two-stage rotary vane pumps in the pumping speed range of 1.25 to 1,920 m^3/h with compact dimensions
- Roots pumps with a high compression ratio and low operating costs adapted flexibly to the specific application
- Mobile leak detectors with a maximum weight of 25 kilograms are powerful and reliablly find every leak.

Our experts are always on hand to assist with configuring the ideal vacuum solutions for your particular use. Please feel free to contact us!

Fig. 6: Portable leak detector MiniTest from Pfeiffer Vacuum and mobile case

VACUUM SOLUTIONS FROM A SINGLE SOURCE

Pfeiffer Vacuum stands for innovative and custom vacuum solutions worldwide, technological perfection, competent advice and reliable service.

COMPLETE RANGE OF PRODUCTS

From a single component to complex systems:
We are the only supplier of vacuum technology that provides a complete product portfolio.

COMPETENCE IN THEORY AND PRACTICE

Benefit from our know-how and our portfolio of training opportunities!
We support you with your plant layout and provide first-class on-site service worldwide.

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Pfeiffer Vacuum GmbH
Headquarters · Germany
T +49 6441 802-0

www.pfeiffer-vacuum.com

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