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Liquid Flow Controller for Methanol

Nitrogen-methanol processes for the heat treatment of steel become more transparent and efficient

Transmission gearwheels are frequently exposed to extreme loads. Generally, in order to counteract premature wear, gearwheels made from steel are surface-hardened. This is carried out primarily by gas carburizing and subsequent quenching (case hardening). These processes of gas carburizing increase the carbon content in the boundary area of the workpiece and change the boundary structure of the steel. In the foundation, Institut für Werkstofftechnik (IWT) (Institute for Materials Engineering) in Bremen, they are engaged intensively with the various processes of heat treatment for the hardening of steel. As an alternative to gas carburizing using endogas, the nitrogen-methanol process, in which liquid methanol is directly introduced into the furnace, plays an important role and is gaining in importance. At the IWT, Liquid Flow Controllers (LFC), from Bürkert Fluid Control Systems, provide regulated and completely documented processes.

During gas carburizing, the surface layer of a workpiece is specifically enriched with carbon, using a C-containing gas at a typical process temperature of 900-930°C. In general, steel for structural purposes that have a relatively low C-content (usually less than 0.25 %) are hardened, which, after the heat treatment, exhibit a hard, wear-resistant surface layer and a tough core. Through the diffusion of additional carbon, the lattice structure in the surface area changes and the austenite substantially metabolizes to the harder martensite. Depending on the size of the component, the processes mainly take between one and 24 hours. In order to attain a high case hardening depth (CHD) of several millimetres, transmission gearwheels for wind power stations that can weigh up to several tons and are exposed to extreme loads, are e.g., carburized for between 12 and 24 hours. In comparison, with the smallest pinions, for example motor vehicle transmissions, a case hardening depth of 0.3 mm is sufficient and for which a substantially shorter process period is adequate. As an approximation, the CHD is proportional to the root of the period of carburization.

The carburization curve is determined by the carbon activity and level of carbon in the carburizing agent. In practice, the C-level in the boundary area is mainly regulated to

Fig. 1: Furnace for heat treatment using various processes at the foundation Institut für Werkstofftechnik (IWT) in Bremen

0.8 percent by weight and, as the temperature, kept constant during the whole process. The C-level is set by the partial pressures for CO and O_2. The partial pressure for CO is determined by the appropriate method of measurement and is, for example, approximately 20 %. The partial pressure of the oxygen is measured using an oxygen probe and used for calculating the C-level. The C-level is regulated in a closed control loop by propane gas control.

During gas carburizing, either endogas or a nitrogen-methanol mixture is primarily used as an applicator of carbon for the furnace atmosphere, because these two processes can be controlled the best. Propane (C_3H_8) and air, ideally dosed using Mass Flow Controllers, provide regulation of the C-level by enrichment and reduction of the carbon content in the gas mixture.

The endogas (20 – 25% CO content as well as H_2, CO_2 and N_2 fractions) is produced from natural gas, propane or methanol by a generator, at approx. 1000°C, by an endothermic and catalytic reaction process.

By using a nitrogen-methanol mixture, the synthetic production of carbonaceous gas for the heat treatment is possible directly in the furnace. This process requires the methanol (CH_3OH) be thermally cracked into hydrogen and carbon monoxide at a furnace temperature of approx. 930°C – a preliminary cracker is not necessary. The liquid methanol is fed directly into the furnace through a lance. At the nozzle, the methanol is changed from the liquid to the gaseous state.

Liquid Flow Controller for Precise Control of Methanol

In the test plant at the Institut für Werkstofftechnik in Bremen, a Bürkert Liquid Flow Controller (LFC) (refer to Fig. 2) takes over the control of methanol, which here, depending on the size of the furnace, is between 3 - 15 l/h. It provides an automatic control of methanol, which reacts to the disturbance variables, such as pressure – either as fluctuating pump pressure in the loop upstream of the LFC, or as pulses in the pipe downstream of the LFC – and always keeps the required dosage of methanol constant through readjustment. The high precision dosage of methanol keeps the operating costs low and guarantees optimum efficiency. In comparison to other flow controllers the LFCs using differential pressure measurement are particularly convincing by means of substantially lower investment costs. Because the measurement principle doesn't require moving parts, such as, e.g. impellers, the exposure to wear is considerably reduced.

Fig. 2: Liquid Flow Controller (LFC) Type 8718 (left, with Profibus communication) and Type 8719 (right, IP65 version)

Especially interesting for the scientists at the institute is the substantially improved knowledge of the process obtained through the recording of methanol consumption and the temporal flow characteristics. „The complete process can be fully documented", emphasizes Dr.-Ing. Heinrich Klümper-Westkamp from the heat treatment department at the IWT. „Within one test series, we can analyze the impact of various process data on the treatment of a component and develop improved reproducible processes."

„During plant operation, the LFCs operate reliably and unproblematic", confirms Ingo Bunjes, Technical Manager of the heat treatment lab at the Bremen Institute. However, in some practices in the use of a Liquid Flow Controller to regulate the methanol need to be considered. The pump pressure in the pipe system should be a minimum of 1.5 to 2 bar overpressure. For a measurement with a good resolution, the LFC's sensor requires approx. 0.4 bar. Operating pressures of more than 2 bar overpressure are also possible, whereby, in practice, methanol supply plants in the heat treatment shop barely exceed 2 bar overpressure. To function well, the control valve should also have at least the pressure drop that the sensor requires. „These pressure drops are maximum values and do not apply to every operating condition", emphasizes Thomas Sattler, application engineer at Bürkert Fluid Control Systems. „Generally, however, a regulating device can only actually influence the flow if it dominates the control system."

Measuring Principle of the Liquid Flow Controller

The measurement of flow through the LFC is based on the differential pressure method, without moving parts in the liquid. A measuring orifice in the main channel generates a pressure drop in the flow from p_1 to p_2 (refer to Fig.3) and is recorded by a differential pressure sensor. A restriction of the flow cross-sectional area causes an increase in the flow velocity and a reduction in the static pressure. The pressure drop is the differential pressure Δp which serves as flow indication. It is proportional to the square of the volume flow: $\Delta p \sim q_V^2$. Independent on the controlling the LFC outputs the flow value measured by the sensor, either analog by a standard signal or digital by fieldbus. For the application-specific design of the volume flow measurement, the decisive parameters are, in addition to the density and viscosity of the liquid at the medium temperature, the nominal flow, the inlet pressure and the differential pressure available.

Determining the Control Element

Solenoid operated, direct-acting, plunger-type proportional valves (refer to Fig. 4) are used as control elements in the Liquid Flow Controllers. The orifices of the valves result from the nominal flow q_{nom}, the pressure conditions within the application, as well as the density and temperature of the methanol. Based on this data, the experts at Bürkert select a solenoid control valve whose flow coefficient k_{Vs}, according to the orifice formula for the specified pressure conditions, permits a maximum flow that conforms at least to the nominal flow required:

$$\mathbf{q_{max}} = \sqrt{\frac{\Delta p * \rho_{H2O}}{\rho}} \; \mathbf{* \, k_{Vs} \; > q_{nom}}$$

Based on the k_{Vs} value, the valve of the LFC can be defined. In the interests of an acceptable operating characteristic of the control section, the defined valve authority Ψ should not be less than 0.3 (refer to Fig. 5).

$$\Psi = \frac{(\Delta p)_{V0}}{(\Delta p)_0} = \frac{k_{Vs}^{\;2}}{[\,k_{Va}^{\;2} + k_{Vs}^{\;2}\,]}$$

While k_{Va} is the k_V value of the control section without a LFC installed, $(\Delta p)_{V0}$ is the pressure drop over the fully opened valve and $(\Delta p)_0$ the pressure drop over the complete section. If the valve authority is too small, the resolution and performance of control could be impaired. The blue curve in Fig. 5 represents such a case. After 40% valve stroke, the volume flow capacity of the valve is almost attained, further stroke has virtually no impact on the volume flow. If the valve authority is too high (grey curve), the valve is not particularly well utilized and the required maximum flow cannot be attained.

The middle, light blue characteristics shown equates to a valve authority of 0.5 which is optimal.

If the operating pressure deviates from the calibrated pressure, or the characteristics of the control valve is heavily influenced, caused by low valve authority, the controller can be readjusted using an integrated autotune function.

Through the integration of the sensor, control electronics and control element in a compact device, the Liquid Flow Controller from Bürkert provides an especially flexible and high performance solution for the regulation of methanol during the nitrogen-methanol processes for the heat treatment of metals. The advantages that direct introduction of methanol into the furnace offer are thus enhanced with substantial additional benefits: Dosing of the methanol is carried out with high precision and is transparent by recording the reproducible consumption and flow values through the LFC and can be fully documented.

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k_{Vs}:	Flow coefficient, in m³/h, when control element is fully open, is measured using water at 1 bar pressure differential over the LFC and a medium temperature of 20°C.
ρ_{H2O}:	Density of the water in kg/m³
ρ:	Density of the operating medium in kg/m³ (referred to same temperature as for the density of the water)
p_1, p_2:	Absolute pressures, in [bar], upstream and downstream of the valve. p_2 results from the inlet pressure of the LFC, minus a pressure differential of 0.4 bar required for the sensor upstream of the valve

$\Delta p = p_1 - p_2$

q_{max}:	Maximum flow through the valve in [m³/h]
q_{nenn}:	Nominal flow through the valve, in [m³/h], at 100% setpoint

$k_v = 0.86 * c_v$

c_v:	Flow coefficient given in US gallons per minute, at a pressure drop of 1 psi and a temperature of 60°F

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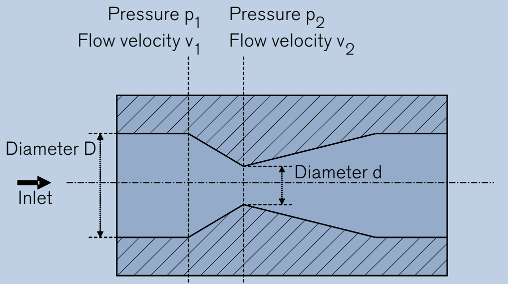

The volume flow

$$q_V = v\,A = v_1 \frac{D^2\pi}{4} = v_2 \frac{d^2\pi}{4}$$

remains constant without additional application of energy. Used in the basic equation for the differential pressure measurement (from the energy conservation law):

$$\Delta p = p_1 - p_2 = \frac{\rho}{2}(v_2^{\,2} - v_1^{\,2})$$

it follows

$$\Delta p = \frac{\rho}{2}\frac{q_V^{\,2}}{A_2^{\,2}}(1 - \frac{d^2}{D^2})$$

or

$$q_V = A_2 \sqrt{\frac{2\Delta p}{\rho(1 - \frac{d^2}{D^2})}}$$

where

q_v:	Volume flow
v:	Flow velocity
A:	Cross-sectional area
A_2:	Cross-sectional area at diameter d
ρ:	Density of the flowing medium

Fig. 3: Measuring orifice for measurement of the differential pressure and conversion to volume flow

Fig. 4: Control valve with 20mm width how it is used in LFCs

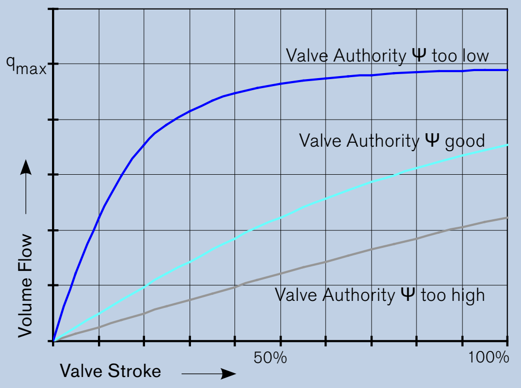

Fig. 5: Flow characteristics caused by varying valve designs