# 1 Basics

## 1.1 Basics and technical implementation of bentonite lubrication systems[1)]

Two basic types of bentonite lubrication systems are differentiated:

- Interval-controlled bentonite lubrication systems, in which the valves are controlled in a defined sequence.
- Volume-controlled bentonite lubrication systems (since 2014), in which the valves are controlled according to configured demand along the route; alternatively, the valves can also be controlled in a defined sequence.

Both systems exist both as systems integrated into the control container or as stand-alone systems.

In general, a lubrication system consists of the parts shown in Fig. 1.1. The first station in the lubrication circuit is the mixing tank, in which the bentonite suspension is dispersed before it is pumped into the storage tank. The bentonite pump supplies the individual lubrication points in the tunnelling machine and in the pipe string.

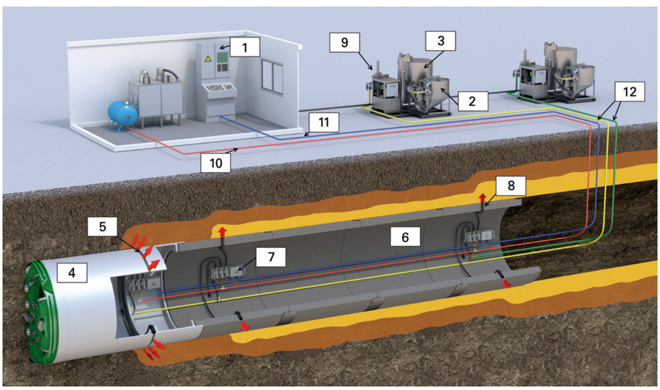


**Fig. 1.1** Principle of construction of the standard Herrenknecht bentonite lubrication system
1: control unit;
2: mixing tank;
3: storage tank;
4: tunnelling machine;
5: lubrication ring;
6: advance pipe;
7: lubrication point;
8: injection fitting;
9: bentonite pump;
10: compressed air supply;
11: control cable;
12: bentonite feed.

In an interval-controlled lubrication system, lubrication cycles are used according to the strategy of the machine driver. A lubrication point (see Fig. 1.2) consists of several injection fittings. The lubrication cycle starts these one after another (e.g. valve 1 – valve 2 – valve 3); thus only one valve is open at any one time. Then the next lubrication point is started.

Generally, normal cycle and extra cycle are differentiated. The normal cycle serves to lubricate the entire tunnel drive. The extra cycle permits in contrast additional control of separately selected lubrication points using the appropriate valves or injection

[1)] All the following statements, descriptions and illustrations refer to the technical systems of the company Herrenknecht AG for automatic bentonite lubrication.

*Bentonite Handbook: Lubrication for Pipe Jacking,* First Edition. Steffen Praetorius, Britta Schößer

fittings. A larger volume of lubricant can be supplied to the machine using the extra cycle. In addition, each lubrication point sends a feedback signal to the control unit, enabling a check whether the individual lubrication point is actually connected.

In a volume-controlled system, the tunnel length is divided into sections each 1 m long. Each of these sections is assigned a configured ideal quantity of suspension depending on the ground conditions. The lubrication system automatically ensures that the connected lubrication points fill these quantities in the corresponding tunnel sections. The individual components of the lubrication system are basically the same for both systems; they are now described in more detail blow.

### 1.1.1 Control unit

The control unit is installed in the container or as a stand-alone unit next to the launching shaft. From here, the machine driver controls the tunnel drive and the lubrication cycle. In principle, the machine driver can select each valve in the entire tunnel drive individually. The (maximum) pump pressure is set directly at the pump.

In interval-controlled operation, the control unit enables two different presets for the valve setting. The first method is called “preset quantity”. In this case a defined bentonite quantity is provided, which should be fed through each valve. As soon as the given quantity has been reached, the valve closes and the next valve is opened. The opening time of the valve in this case follows from the flow rate of the bentonite suspension, so a flow meter and pressure measurement unit is required for this control variant, which is connected directly to the control unit. It has the task of recording the flow quantity and sending it to the control unit. For this purpose, a magnetic-inductive flow meter (MID) is often used. This instrument is based on the fact that the suspension flows through a magnetic field and thus induces a voltage, which is recorded by two electrodes.

The second method of valve control is called “preset time”. This permits the valves to be opened for a defined time. In this case it does not matter what volume of bentonite flows through the valve in this time; this can be different for each valve.

Another important setting, which the machine driver undertakes from the control unit, is the selection of normal or extra cycle.

### 1.1.2 Mixing tank

The mixing tank can be set up either separately or directly next to the control unit. It mixes the bentonite suspension (lubricant). Its size depends on the quantity of bentonite suspension needed in the course of the tunnel drive. The mixer is connected to the mixing tank or directly integrated into it. The mixer consists of a shear impeller, rotating shear arms or a venturi system.

The mixing tank can be fitted with electronic flow meters and/or modules for electronic data logging for better control and monitoring.

### 1.1.3 Storage tank

The storage tank is similar to the mixing tank. It is often fitted with an agitator or recirculation equipment and is used for intermediate storage of the bentonite. The storage tank ensures that a constant bentonite flow and a constant bentonite quality can be guaranteed by maintaining a configured hydration time.

### 1.1.4 Main jacking station

The main jacking station is a hydraulic advance device to provide the necessary jacking force; it is installed in the launching shaft. The main jacking station consists of the jacking frame, the thrust cylinders, a pressure ring and the jacking abutment.

### 1.1.5 Tunnelling machine

The tunnelling machine consists of cutting head and steering head as well as backups or machine pipes.

### 1.1.6 Lubrication ring

The lubrication ring is located at the end of the machine or between two machine pipe sections. From here, the bentonite is distributed around the entire circumference of the machine independent of the number of feed pipes.

### 1.1.7 Intermediate jacking station

In pipe jacking, an intermediate jacking station (interjack) is usually installed about every 80–90 m. Some additional jacking cylinders integrated into a steel sleeve pipe is placed between the lead pipe and the trail pipe of the intermediate jacking station. The use of intermediate jacking stations divides the total pipe jack into several sections. The entire jacking force of the main jacking station is thus distributed to the individual sections and reduced in total.

### 1.1.8 Jacked pipe

The jacked pipe is a prefabricated pipe with a movable or rigid connection inside the wall thickness capable of transferring compression force, tension force or compression and tension force and a smooth, flat outside contour. It is jacked, pushed or pulled into the ground.

### 1.1.9 Lubrication station

The first lubrication should be installed as near as possible behind the tunnelling machine. Normally every third or fourth pipe is used as a bentonite pipe. With an average pipe length of 3 m, this means a bentonite lubrication station is installed every 9–12 m.

The bentonite lubrication station are controlled by the control unit. The lubrication station consist of a valve block with three actuated ball valves. The lubrication station is connected through a 28L, 2″ or 3″ bentonite feed line. The injection fittings are connected to the lubrication station through a 22L hose. The main piston of the valve is opened by compressed air so that the bentonite suspension can flow to the selected lubrication station (Fig. 1.2).

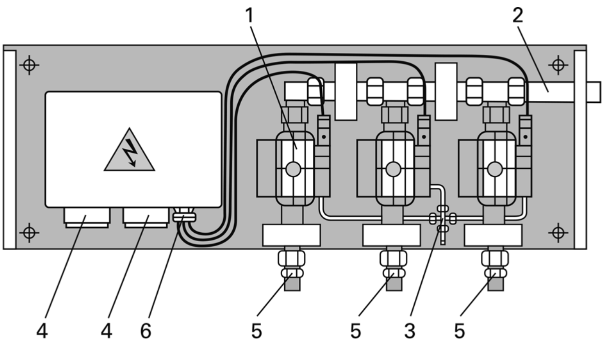


**Fig. 1.2** Herrenknecht system lubrication station. (Source: Herrenknecht AG). 1: Compressed air-controlled valve; 2: Connection to tunnel line; 3: Connection to compressed air line; 4: Electric connection; 5: Outflow to bentonite nozzles; 6: Control cable to bentonite valve.

### 1.1.10 Injection fittings

At each lubrication station, there are three injection fittings, which are individually controlled by valves. The injection fittings should be distributed as uniformly as possible around the pipe. They are normally mounted at 12, 4 and 8 positions on a clock face (Fig. 1.3).

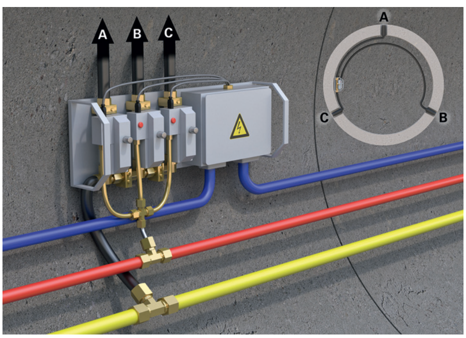


**Fig. 1.3** Lubrication point in pipe string and distribution of the injection fittings around the cross-section. (Source: Herrenknecht AG).

### 1.1.11 Bentonite pump

The bentonite pump serves to regulate and maintain the pressure and the flow. In order to hold the pressure in the pipe as constant as possible, pressure losses have to be minimised. These depend on the type and length of the pipe and the viscosity of the bentonite. Various types of pump are used, e.g. piston pumps or screw pumps.

### 1.1.12 Compressed air feed

The compressed air feed has an internal diameter of 13 mm and an external diameter of 19 mm. The hoses and couplings can resist a pressure of up to 10 bar. The compressed air feed supplies the actuated valves with the necessary energy. A branch leads to each bentonite lubrication point, which is connected with T-piece (Fig. 1.4).

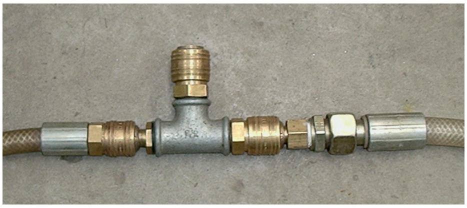

**Fig. 1.4** Branch from the compressed air feed pipe to an individual lubrication point. (Source: Herrenknecht AG).

### 1.1.13 Control cable

The control cables connect the control unit to the individual lubrication points. Up to 80 points can be controlled from each control cable run.

### 1.1.14 Bentonite or feed line

The bentonite or feed line connects the bentonite pump with all bentonite stations and runs to the machine. At each of the lubrication stations, there are T-branches, which lead through the lubrication stations to the individual valves and injection fittings. The bentonite line mostly consists of 28L hoses or 2″, 3″ or 5″ steel pipes.

The lubrication stations are connected to the branches (T-pieces) from the bentonite line. A 22 L hose is laid to the individual injection fittings.

## 1.2 Annular gap lubrication in pipe jacking

In pipe jacking, lubricant is injected into the annular gap in order to reduce friction between the jacked pipe or pipe string and the surrounding ground. This friction is described as skin friction, and can be reduced by various measures [81]:

- The radial loading on the casing surface area can be reduced by maintaining an annular gap. The undisturbed soil is supported so that the surrounding ground has as little contact area with the jacked pipe as possible.
- The friction coefficient $\mu$ between jacked pipe and ground can be reduced by the formation of a layer of sliding medium.

The selection of a lubricant is determined by the properties of the ground, i.e. its geological, hydrogeological properties and any contamination. The fundamental properties of soft ground and rock are summarised below. For the lubrication, the significant parameters are stability, permeability and size of the porosity in soft ground, and the size of the joint opening width in rock. The rheological properties of the bentonite suspension used as a lubricant – yield point, viscosity and gel strength – have to be adapted to these constraints. The size of the bentonite particles in the suspension is a physical property, which has a decisive influence on the formation of the support mechanism in the soil.

Basically, the bentonite suspension in the annular gap has to fulfil the following three functions:

– Support the excavated cavity
– Lubricate the pipe string
– Keep ground particles buoyant in suspension

These basic functions occur in combination depending on the type of ground, as will be described in more detail below. First it makes sense to state the special features and constraints of bentonite lubrication in pipe jacking:

– The lubricant is injected into the annular gap once and remains there permanently. It is very laborious and often impossible to change or adapt the suspension subsequently.
– In the annular gap, flow processes occur within tight spatial limits.
– Since the pipe jacking process normally lasts a matter of weeks and the pipe string is repeatedly in movement during this time, time effects are significant with regard to the changes to suspension consistency and flow process into the surrounding ground.
– The geological conditions along the jacked distance are usually inhomogeneous.

## 1.3 Preliminary remarks about the ground

In the currently applicable standards and guidelines, soil classifications are undertaken with the aim of finding a group classification of soils with specified features and criteria for construction purposes. A soil group thus includes soil types with approximately similar material structure and similar construction properties, i.e. the soil classification does not deliver any purely material information.

In order to determine the properties of soil and rock for pipe jacking, not only the laboratory and field classification tests such as grain size distribution, plastic limits, water content and density, but also in particular tests to determine the shear strength, permeability and stiffness as well as the swelling pressure behaviour of swelling soils are all important. The performance of tests is regulated in the soil mechanics standard DIN 18121–18137. DIN 1054 [16] and EN ISO 14688 [25] (which replaced DIN 4022 in 2002) offer information about the description of rocks, although no detailed categorisation of solid rocks is given since the rock mass properties are normally of more significance for construction than the rock properties.

According to DIN 18319 "Trenchless pipe laying methods" [34], the ground is divided into soil and rock and is classified into various classes according to its properties (Tables 1.1 to 1.3):

– Non-cohesive soils according to their grain size distribution and consolidation
– Cohesive soils according to their consistency

– Additional classes to describe the plasticity
– Additional classes for stone and block contents
– Rock according to tis uniaxial compression strength and its joint spacing

**Table 1.1** Summary of the classification of non-cohesive spoils (main components sand, gravel or sand and gravel with cohesive content, grain size up to 63 mm) according to DIN 18319 [34].

| Consolidation | Class | | |
|---|---|---|---|
| | Fine grains[a)] ≤15 % by mass | | Fine grains[a)] >15 % by mass |
| | closely graded | widely or inter-mittently graded | |
| loose | LNE 1 | LNW 1 | LN 1 |
| medium dense | LNE 2 | LNW 2 | LN 2 |
| dense | LNE 3 | LNW 3 | LN 3 |

a) Grain size up to 0.063 mm.

**Tabel 1.2.1** Summary of the classification of cohesive soils (main components silt or clay, grain size up to 63 mm) according to DIN 18319 [34].

| Consistency | Class | |
|---|---|---|
| | mineral | organogenic |
| pasty to soft | LBM 1 | LBO 1 |
| stiff to semi-solid | LBM 2 | LBO 2 |
| solid | LBM 3 | LBO 3 |

**Table 1.2.2** Summary of the classification of cohesive soils according to DIN 18319 [34]: additional classes for the description of plasticity.

| Plasticity | Additional class |
|---|---|
| light to medium | P 1 |
| pronounced | P 2 |

**Tabelle 1.2.3** Summary of the classification of cohesive soils according to DIN 18319 [34]: additional classes for the description of stone and block content.

| Grain size | Additional class | |
|---|---|---|
| | up to 30 % by volume | over 30 % by volume |
| over 63 mm to 200 mm | S 1 | S 2 |
| over 63 mm to 630 mm | S 3 | S 4 |

**Table 1.3** Summary of the classification of rock according to DIN 18319 [34].

| Uniaxial compression strength in the advance direction [N/mm²] | Class | |
|---|---|---|
| | fissure spacing ≤10 cm | fissure spacing >10 cm |
| up to 20 | FZ 1 | FD 1 |
| over 20 to 50 | FZ 2 | FD 2 |
| over 50 to 100 | FZ 3 | FD 3 |
| over 100 to 200 | FZ 4 | FD 4 |