Safety for human beings and pipelines: a new approach in workshop design

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Abstract

Traditionally in workshops conflicts arise between requirements for the safety of human beings and requirements to prevent stray currents. Within workshops more strict limits for step and touch voltages apply than for the rest of the railway system. These requirements can be met in case the running rails are connected to ground, but this will increase stray currents.

As The Netherlands is a very densely populated area, for reasons of economy of space nowadays infrastructure is more often bundled. This can lead to an increase of interference between various infrastructure components. In the case of the new workshop and stabling yard “Beverwaard” the functions of workshop and stabling yard have been combined with a parking garage, while at the same time a number of high capacity, high pressure gas transportation pipelines and a major highway are in close vicinity. The classical approach of grounding the running rails can no longer be followed, as this would lead to an increase of stray currents in the soil, which is not admissible due to the pipelines close by. Therefore a new concept has been developed which can meet all requirements.

The new concept has been based on an integral earthing concept, integrating safety earthing, lightning protection and using civil structural assets, based on the philosophy of IEC 61000-5-2 [1], which has excellent EMC properties. Running rails are insulated from the substructure, and grounded at one location. A rigorous bonding strategy ensures very low step and touch voltages. With respect to traction power supply the workshop is an island, fed from a dedicated substation. A benefit of the concept chosen is that complex machinery as a wheel lathe can be incorporated in the design in a relatively easy way. For the insulation of running rails a new approach has been chosen: to use PUR foam, as this is both light and is insulating. Measurements of the insulation quality have been performed over a long period of time to assure that the insulation quality is stable over time, even in very wet adverse conditions.

Simulations have been performed to determine the effect of the chosen solution on the adjacent pipelines. Both the starting situation (without workshop) as well as the end situation (with workshop) have been studied. For the simulations the Movares tool STARTRACK [2] has been used.

It can be concluded that it is possible to integrate railway infrastructure with susceptible pipelines and at the same time guarantee safety of human beings and installations.

Introduction

South of Rotterdam RET (Rotterdam Municipal Transport) is realising the project “Beverwaard”. This project consists of a workshop, combined with a stabling yard, park & ride accommodation with 500 parking places and a transferium, leading to multifunctional use of the available space, which is always an important issue in a densely populated area such as The Netherlands.

Goal is to create a project which fits in with the surrounding landscape with minimal influence on the environment. Therefore solar panels will be included in the design, and special waste water treatment is foreseen. The location of “Beverwaard” has been chosen because of the existing tramline (600 V d.c.), and the vicinity of a major highway and other important secondary roads. An artist impression of the entire project can be found in Figure 1.
Design Challenges

A main design challenge from an electrotechnical point of view can be seen in Figure 2. The location of the workshop is very close to a major high pressure, high capacity gas pipeline. As the pipeline in its original state was crossing the previewed location of the workshop, a detour has been made. Unfortunately, the detour is only minimal, so from a stray current point of view, the pipeline is still quite close.

In the original situation some influence of the existing tramway on the pipeline was present, but within the limits as specified by [3]. Of course in the new situation this must also be the case, and will have to be proven by measurements. Given the fact it is very important that no surprises arise when these measurements are performed, a comparison has been made for the original situation and the new one using simulations.

Another major design challenge is the fact that the limits for step and touch voltages in workshops are more restrictive as for “normal railways”, normally 120 V d.c. permanent is allowed, whereas in
workshops only 60 V d.c. is allowed by [4]. However it is known from practical experience in The Netherlands that even when the step and touch voltages are relatively low (much lower than 60 V), the sparking phenomena, which can be observed when a grounded object touches a floating rail, can lead to problems with the staff of the workshop, even leading to “improvised” earthing of the rails by the staff.

**Conceptual Design**

In Figure 3 an overview can be found of the different concepts used in the past:

A. Running rails are insulated (floating); an insulator is present in catenary, interlocked with the earthing switch. The advantage is a simple installation, and stray currents can be controlled, but step and touch voltages can be problematic.

B. Running rails are grounded. Extra insulating gaps in the rail are necessary, bridged by contactors, which need to be interlocked with the switches in the catenary. Of course the earthing switch needs to be interlocked with the catenary switches as well. The installation becomes more complex, but step and touch voltages can be controlled. Disadvantage is that during the entering and leaving of vehicles of the workshop, stray currents can arise.

![Figure 3 Earthing concepts used in the past](image)

In Figure 4 an overview can be found of the concept developed for the workshop “Beverwaard”. The concept is based on the philosophy of IEC 61000-5-2 [1], and combines features of both concepts presented in Figure 3. Main characteristics are:

- The entire workshop and stabling yard is insulated from the remaining network, both rails and catenary;
- The workshop and stabling yard have their own dedicated traction substation;
- Switches are present to feed the workshop and stabling yard from the remaining network only in emergency situations;
- The reinforcement of the foundation and civil structure is welded together to form one big conductive structure (parking deck is also galvanically coupled);
- Lightning protection is integrated with the reinforcement;
- The PEN network of the building is connected to the reinforcement;
- Running rails are generally insulated from the reinforcement, but connected at one location to the main earth bar. Multiple cables are used;
- The negative busbar of the substation is also connected to this main earth bar;
- The star-point of the 400 V windings of the 10 kV transformer feeding the workshop and the stabling yard is also connected to this main earth bar.

![Figure 4 Concept developed for the workshop “Beverwaard”](image)
Challenge B: An environmentally friendly railway

Due to the fact that the running rails are insulated from earth (or the reinforcement) all along the system, stray currents are minimised. Also a large conductive structure is present, the entire building, including the foundation, which also is beneficial for stray currents. Running rails are connected using many parallel cables the negative busbar of the substation which is connected to the main earth bar, thus controlling step and touch voltages. For an overview see Figure 5. Also the stray currents coming back to the negative busbar from the earthing system are monitored. Formally [5] requires rails to be insulated from earth, however an exception is made when earthing is needed for human safety.

As all the reinforcement of the building is welded together and connected to earth at multiple locations, it will function as a Parallel Ground Conductor (PGC) as defined in [1], thus reducing disturbances coupled into cabling, which is usually close to structural elements of the building. A benefit of the concept chosen is that complex machinery as a wheel lathe can be incorporated in the design in a relatively easy way, as no insulation from reinforcement or isolation transformers are needed.
Insulation Test

As mentioned earlier rails need to be insulated. Thus the need arose for a good rail insulation method which is both cheap, has a low weight and can be applied easily.

![Diagram of test set-up for insulation test of PUR rail insulation]

**Figure 6 Test set-up for insulation test of PUR rail insulation**

The suggestion was made by the track department of RET to use PUR foam, but as the insulation properties of this material under adverse conditions are not known, a test set-up was developed, see Figure 6. The set up consist of a tank filled with a saturated solution of CuSO$_4$ in water, in which the test object is partly immersed. A copper ring forms one electrode, whereas the rail is the other electrode. An auxiliary electrode is present to measure the resistance of the solution. Gravel was added to support the test object and to reduce the amount of water needed. An overview of the test set-up can be found in Figure 7. Results can be found in Figure 8.

![Image of the test set-up for insulation test PUR]

**Figure 7 Realisation of test set-up for insulation test PUR**

Two samples with a length of 1 m were tested. For sample A the PUR coating was applied in two layers, for sample B first a noxide coating was applied, covered by one layer of PUR with a same thickness as the two layers of sample B. From the tests it can be observed that the initial resistance of sample A was very high, but soon a discharge was observed, after which the resistance dropped considerably. At day 10 sample A was lifted partially out of the water, a rise in resistance can be seen. For sample B a similar behaviour can be observed, although the drop in resistance is more gradual.
The resistance between the auxiliary electrode and the ring was approximately 2 Ohms, so it can be proven that the resistance of the water has a only a minimal influence on the measurement.

![Insulation test graph](image)

**Figure 8 Results of insulation test PUR**

The explanation of the behaviour observed is that PUR itself insulates very well, but that water intrusion between the layers of PUR (especially sample A) leads to a deterioration of the resistance. This was corroborated when the sample was dismantled, and a layer sawn off, clearly traces of water intrusion and contamination could be observed, see Figure 9. From sample B it can be concluded that the noxide coating has a beneficial effect, same as the use of a single layer.

![Cross section of sample A](image)

**Figure 9 Cross section of sample A with traces of water intrusion**

From the measurements the conclusion can be drawn that, in combination with a noxide coating and if applied in one layer, PUR has reasonable insulation properties, provided it is not subjected to extreme wet and polluted conditions on a permanent basis. The reversibility of the deterioration process has been proven by the partial lifting of sample A, after drying out, resistance rose considerably.

Therefore in those locations where PUR is used (for instance in the workshop) care has been taken in the design to prevent permanent water intrusion by applying a waterproof floor, taking care of water draining etcetera.
Simulations

For the simulations the tool STARTRACK (Movares in house developed) has been used. A detailed description of this tool can be found in [2], so here only a limited description will be given.

The model consists of 2-D sections, which are coupled longitudinally. In a section the galvanic coupling between elements through the soil is taken into account. Each element is modelled as a half spherical earth electrode, soil is modelled as a half infinite space with a constant resistivity (although the model is able to take multi-layers into account), see Figure 10. This leads to transversal coupling coefficients between elements. Longitudinal coupling is also taken into account, which leads to the complete model, see Figure 11.

The actual situation present is implemented in the model in a simplified manner in order to obtain a realistic simulation effort. A large number of simulations has been performed:

- Situation without and with workshop and stabling yard;
- Normal power supply situation and emergency feeding from the main line;
- Different load positions;
- Rail to earth conductance varies between 2.5 Ohm.km and 100 Ohm.km;
- Pipeline intact and small defects present;
- Etcetera.

For reasons of brevity here only a limited amount of results can be shown. We concentrate on the normal operating conditions, workshop and stabling yard are fed from it’s own substation. Rail to earth conductance is 2.5 Ohm.km. Main parameter to be considered is the amount of stray current on the pipeline. Two situations will be compared, without and with workshop and stabling yard. In Figure 12 an overview can be found of the current distribution in the situation with the workshop and stabling yard present.
A more detailed view of the current in the earth and on the pipeline can be seen in Figure 13. As it can be seen the amount of stray current on the pipeline is not very high in the situation with the workshop and the stabling yard present, only 1.5 mA.

In Figure 14 a detailed view of the current in earth and on the pipeline is given for the original situation. As it can be seen the amount of stray current on the pipeline is also not very high in the original situation, only 5 mA. This is in line with the practical experience before the workshop project started. In fact stray current in the pipeline has been reduced by the introduction of the workshop, due to the fact that now another large conductive structure (the foundation of the building) is present.
As it can be seen from Figures 13 and 14, the current only flows on a discrete part of the pipeline. This is due to the fact that the pipeline is coated with an insulating layer. In the model, at two (worst-case) locations, defects in the coating have been introduced in the insulating layer, as this most common case in practice that leads to stray current problems. As the realisation of the project is still ongoing at the moment, these simulation results still have to be checked by measurements, but the concept developed is very promising.

Conclusions

Based on the above it can be concluded that is possible to guarantee safety for both human beings as well as for pipelines, even in a complex situation where a workshop is in the close vicinity of a pipeline. Stray currents can be controlled by a Parallel Ground Conductor, in combination with a dedicated substation. The application of IEC 61000-5-2 and the concept developed have good EMC properties, and enable an easy integration of large (wheel lathe) and sensitive (control computers) electrical equipment.

It has been proven that PUR can be used as insulation material for running rail, provided that care will be taken in the track design to prevent water intrusion and good water drainage is present. The use of simulation tools like STARTRACK has proven to be very helpful, especially in comparing the effects of different designs on the amount of stray currents in third party assets. Unfortunately, the complete result, including final measurements cannot be given here at this moment, as the realisation of the workshop and stabling yard is still ongoing at this moment.

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References


