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Research Article

Analyzing of Stray Current Interference on Buried Gas Pipeline from Shanghai Urban Rail Transit

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Abstract: With the fast development of urban transit system and natural gas industry, the Stray Current Corrosion (SCC) for buried gas pipeline has become more frequent in china. In this study, principle and characteristic of Stray Current (SC) resulting from rail transit system were introduced. Presently available SC testing methods, equipment and determination standards in china were summarized. For an underground gas pipeline located in the neighboring area and parallel to the rail transit in Shanghai, pipe-to-soil potential, potential gradient of soil, current within pipeline were measured during different operation time of rail transit with a self-made SC monitoring system based upon virtual instrument. Result shows that pipe-to-soil potential fluctuation of the tested gas pipeline is 200 mV, current within pipeline and potential gradient of soil is 100 mA and 62 mV/m, respectively, which is consistent with the operation of rail transit, serious corrosion of the buried gas pipeline may occur. Through theoretical Analysis, several protective measures were introduced.

Keywords: Current within pipeline, gas pipeline, pipe-to-soil potential, potential gradient, rail transit, stray current

INTRODUCTION

Stray Current Corrosion (SCC) caused by Stray Current (SC), which deviates from their intended path, is the most severe form of electrochemical corrosion to buried metallic structures. SCs may originate from electric railways, urban rail transit traction, electric welding equipment, electric transmission lines and cathodic protection systems (Uhlig, 1985) and Direct Current (DC) rail transit traction systems are the largest SC sources for urban buried gas pipeline. In past decade urban rail transit systems have been developing rapidly in China, meanwhile natural gas industry expands at the same astonishing pace, more and more underground steel gas pipelines have been buried intersecting with or parallel to rails, SCCs resulting from rail systems have become more frequent, especially in those areas where underground pipelines, cables, are densely distributed. Due to the fact that SCC had for a long time been proved to be a hazard to neighboring metal structures (within and outside rail systems) (Bertolini *et al*., 2007), operators of both rail transit and gas pipelines set up strict technical codes to minimize SC damage (Sim and Chan, 2004), but subject to the backward domestic industry and construction management level and the aging of protective measures, stray current corrosion problems still may occur (Cheng *et al*., 2003). For a 10-year-old underground Φ300 steel gas pipeline, located in the neighboring area and parallel to the rail transit powered by a DC source in Shanghai, corrosion accident occurred many times in recent years. SC may exist with the frequent and short cycle corrosion which is needed to be verified.

For D.C. rail transits system, the driving current changes continuously, so is the SC, the transient characteristic leads to more difficulty for determination and protection of SC. In the study, a stray current monitoring system based on virtual instrument was developed. Using this system pipe-to-soil potential, potential gradient and current within pipeline of the buried gas pipeline located in the neighboring area of the rail transit in Shanghai were measured and analyzed.

MATERIAL AND METHODS

Mechanism and Detection of SC from rail transit Urban rails systems, including subway, elevated light rail, trams etc., are driven by Direct Current (DC) at 750V/1500V. Figure 1 shows typical mechanism of stray current interference from DC traction power systems. The driving current flows along the catenary wire, through the traction motors and back to the traction power substation along the running rails. The rail-to-ground resistance cannot be made infinite and the rail resistance is not zero, part of driven current deviates from designed path and escapes into the earth, resulting in SC. The SC may flow into the underground structure and return to the rails or negative feeder taps in the vicinity of the substation or power plant. The corrosion happens where the current discharging. Through the current circuit, stray current will cause severe corrosion attacking on buried metallic structure,

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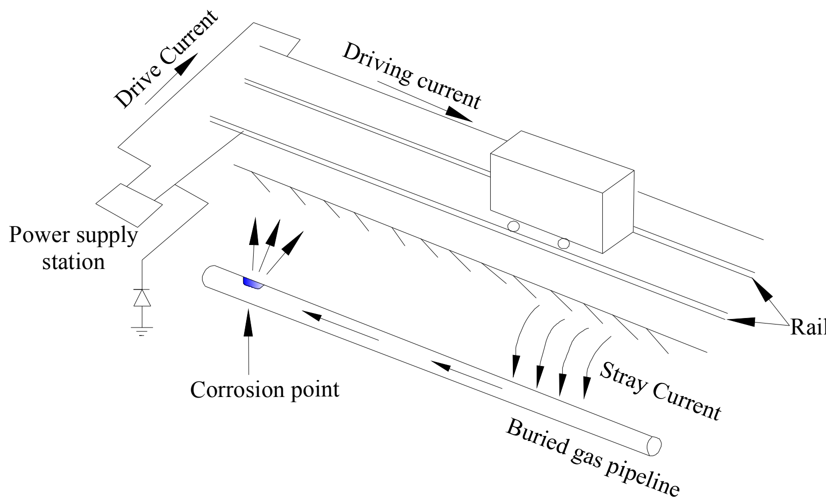

Fig. 1: The mechanism of stray current from rail transit traction system

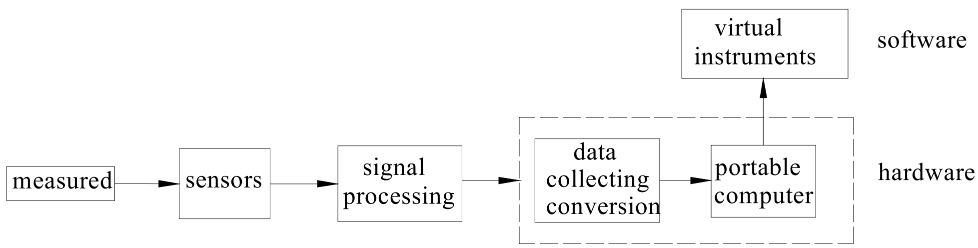

Fig. 2: Operational principle of monitoring system

as well as on facilities belonging to the transit system itself (Li, 2004).

The best approach to assess SC interference is to determine the change in current density. It is not an easy task for SC from rail transit system, due to the complexity and uncertainty of propagation paths and influencing factors. The potential of pipe-to-soil and gradient of soil is always changing, when the currents flow out, so through the changes of the potential magnitude the stray current can be estimated, now commonly used methods include pipe-to-soil potential test, close-interval potential testing techniques (CIPS) and DC potential gradient test. According to Chinese National Standard GB/T 19285-2003 ”inspection of corrosion protection for buried steel pipelines”, when the positive shift of pipe-to-soil potential is higher than 20 mV or the potential gradient of soil is higher than 0.5 mV/m, direct current SC corrosion can be considered to be existent. When the positive shift of the pipe-to-soil potential is higher than 100 mV or the potential gradient of soil is higher than 2.5 mV/m, electrical drainage or other protective measure must be carried out.

The SC monitoring system: The intensity and flow direction of SC is directly related to the running mode of the rail transit, the insulation resistance between rail and earth, the resistance of pipeline coatings, soil resistivity, etc. Between two stations, the train will go through acceleration, coasting and deceleration, the driving current is fluctuating continuously and so is the SC. Considering the bi-directional operation, it is more complex. Dynamic properties of SC lead to the necessity of high accuracy and high-frequency monitoring system.

Currently there are a number of automatic SC monitoring systems available in china, such as the ZSNJ-I on-line Automatic stray current monitoring system used in Guangzhou Metro Line1 (Zhao and Li, 2001), the automatic potential monitoring system used in Shanghai Pearl Line (Li *et al*., 2001), the stray current monitoring systems used in Dalian light railway 3 (Xu, 2004). However, all of the present automatic monitoring system focus on the interference of SC upon facilities belonging to the transit system, concerning about the rail-to-soil potential, current through the rail, current changes in drainage net etc. and the testing frequency is less than 1Hz. Up to now there is no suitable monitoring system for the buried pipelines. For the city gas utility company, the monitoring and detection methods of SC still remain quite old, periodically measuring pipe-to-soil potential by means of test piles and a voltage meter. The traditional method cannot meet the high-frequency and high precision requirement for SC from rail transit system.

Accordingly a monitoring system based upon virtual instrument was developed to capture the fast changing SC. The system consists of portable computer, sampling chipset, reference electrodes and data transfer line. Saturated Copper-Copper-Sulphate Electrode (CSE) is used for test of pipe-to-soil potential and potential gradient of soil, with the character of voltage stability, long service life and small internal impedance. The data acquisition model is a 16-bit, 8-channel analog input module that provides programmable input ranges on all channels. It offers signal conditioning, A/D conversion and RS-485 digital communication functions, with main specifications: 8 differential Channels, different input type including mV/V/mA, many input ranges including ±150 mV~±10 V/±20 mA, Sampling Rate 10 sample/second (total) and so on. With figure programming language Lab VIEW, real-time waveform display, frequency control and automatic storage of the testing potential can be achieved.

Figure 2 shows the principle of the system. The real-time waveform of SC can be displayed and recorded. The sampling frequency can reach 10 Hz or more, depending on the capability of different sampling chipset (Chen *et al*., 2010).

Experimental: By means of developed system, pipe-to-soil potential, potential gradient of soil and current within gas pipeline were measured during different operation time of rail transit, to verify the existence of SC and the relevance between SC interference and the running of subway. Testing schematic diagram is like Fig. 3.

The tested gas pipeline is parallel to the rail transit with distance of 10 m. Pipeline depth is 2 m:

- Three test points (named 1, 2, 3) were selected for pipe-to-soil potential with intervals of 50 m. To eliminate the influence of IR drop, permanent saturated Copper-Copper Sulphate Electrode (CSE) was used, buried 10 cm above the pipeline
- Electric potential gradient of soil is the vector addition of the horizontal and vertical potential gradient in the same point, tested through four temporary CSEs distributed perpendicular to each other with 1m intervals, respectively, in green belt along road
- For buried gas pipeline, the current cannot be measured directly unless the test piles had been built during the initial construction. Due to the fact that SC corrosion had led to frequent gas leakage accidents, Gas Company decided to abandon steel pipes in the measured area and replace it by PE pipes. During this construction process, the buried steel gas pipeline was divided into several insulated segments, with the test piles and switch between the insulation joints. By this technical approach, measurement of current within the pipeline became feasible. Using automatic recording ampere meter, currents within pipes were measured at three points (A1, A2, A3) and sampling frequency was 1Hz.

RESULTS AND DISCUSSION

The pipe-to-soil potential test: The magnitude of the SC changes can be reflected and evaluated through pipe-to-soil potentials. Tests were made for different operation modes of subway, namely, bi-directional operation, unidirectional operation and non-operation. The average values recorded during the non-operation period was considered to be the natural potential.

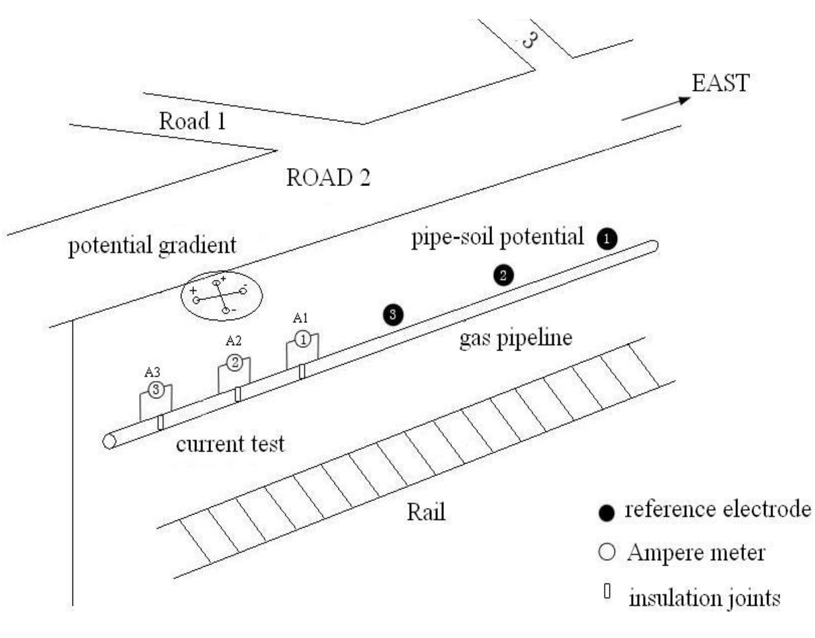

Fig. 3: Testing schematic diagram of pipeline-soil potential, current in pipeline and potential gradient of soil

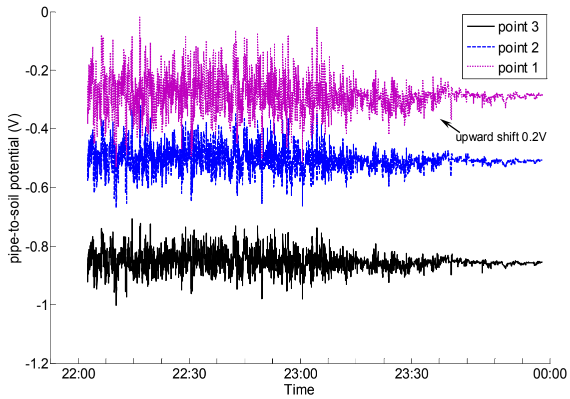

Fig. 4: The variety of pipe-to-soil potentials vs. time

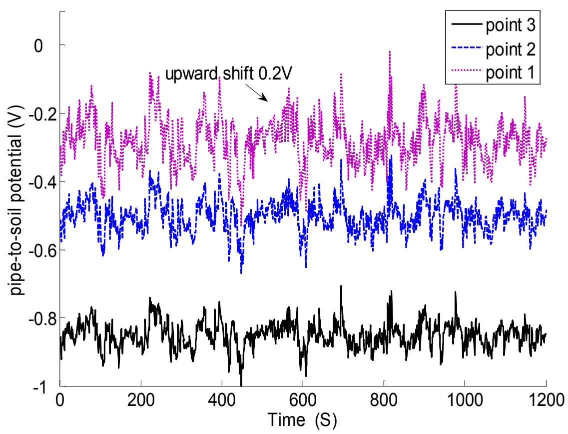

Fig. 5: The pipe-to-soil potentials during bidirectional operation

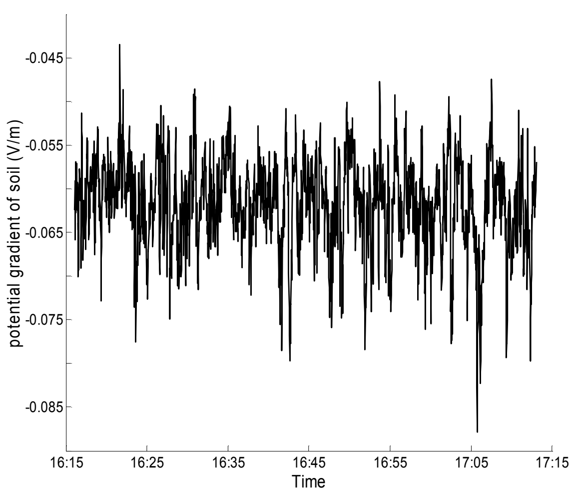

Fig. 6: The variety of potential gradient of soil

Figure 4 shows pipe-to-soil potential changes of 3 points versus time, in order to avoid overlap and easy to observe, the curve of point 1 is integral translation in +0.2V compare to the measured value. The different time periods are 22:00~22:30, 22:30~23:30 and 23:30 later, corresponding to the different running periods of subway.

It can be found that pipe-to-soil potential of the tested gas pipeline fluctuates dramatically. During the bi-directional operation of the subway, the positive shift of the average potential is approximately 40mV and the maximum positive shift of the potential reaches 200 mV, much higher than that prescribed in national standard (100 mV). With subway operation becoming less frequent from bidirectional operation to unidirectional operation, the average value of pipe-to-soil potential of point 1 drops from -0.458V to -0.471V, the average positive shift is from 0.037 V to 0.024 V and the SC interference is decreasing, so is point 2 and point 3.When the subway stopped running, the fluctuations of pipe-to-soil potential become flat. All the results indicate that the measured gas pipeline is in danger of serious SCC and the fluctuation of pipe-soil potential is found to be synchronous with the operation of subway.

The average potential of both point 1 and point 2 (slightly above -0.5V) are much higher than the requirements of national standard (-0.85V), corrosion hazard may occur at point 1and point 2, protective measures must be considered.

Figure 5 is the variation of pipe-to-soil potentials within 20 minutes during bidirectional operation of subway with the upward shift 0.2V of point 1. It can be found that the curve of the potential changes in a quasi-periodical mode, almost two and a half minutes, which is consistent with the operation of rail transit in peak load, but the pipe-to-soil potentials fluctuate frequently with different running trains and also are influenced by some background interference, the regularity needs further analysis.

Test of electric potential gradient of soil: Measurement of potential gradient of soil can identify coating defects and also can determine the direction and size of SC. Based on the results of pipe-to-soil potential test, potential gradient of soil tests were taken to verify the presence of SC and its direction. Test time is 16:15~17:15, when the rail transit is running normally. Figure 6 and Table 1 show the variation of Potential gradient versus time, Fig. 7 shows the distribution of reference electrode and the direction of potential gradient.

From Fig. 6 and Table 1, it can be found that the average value of measured potential gradient of soil is 62 mV/m, much higher than that prescribed in national standard (2.5 mV/m) and the potential gradient fluctuates frequently, the maximum shift can reach 25 mV/m, all result indicate the presence of stray current interference.

Table 1: The potential gradient of soil and its direction in testing point

	Horizontal potential gradient (mV/m)	Vertical potential gradient (mV/m)	Potential gradient of soil (mV/m)	Tangent value of angle with the horizontal
Average value	-56.89	-24.05	-62	0.4508
Minimum value	-87	-34	-87.9	
Maximum value	-33	-13	-43.5	

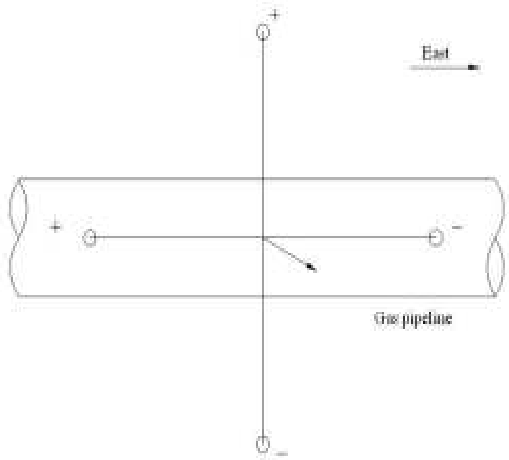

Fig. 7: The direction of potential gradient

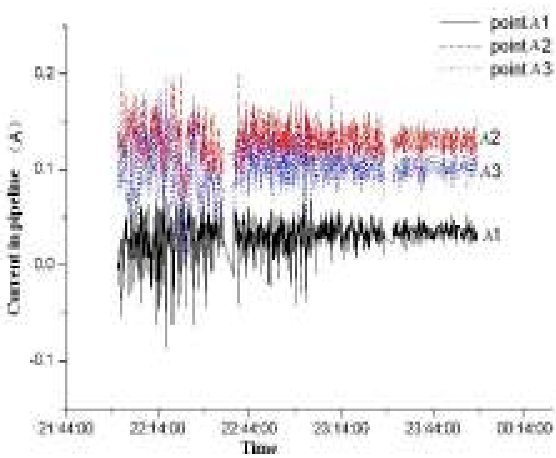

Fig. 8: The variation of current in the gas pipeline with time

Through vector graphics system in Fig. 7, we can see the direction of potential gradient is southeast, with an angle of 24.2 degrees from horizontal, it means that the current in soil mainly flows to east.

Test of current within pipeline: Figure 8 shows the variations of current within pipes at 3 points, testing time from 22:00 to 0:05, including different subway running periods. During the operation of subway, the current within pipeline can be found to be seriously fluctuating, the maximum was 150 mA. With the subway operation becoming less frequent, the fluctuations become smaller. Finally the current changes tend to be flat, when the subway stops running after 23:30. Results of the current test also indicate that the measured gas pipeline is in danger of serious SC corrosion.

The average value of the current at point A1, A2, A3 was 30 mA, 150 mA and 120 mA, respectively. There was a great difference between point 2 and point 1. Through the investigation of the power station for railway systems, a transformer substation was found to be in the vicinity of point A1 and the overall direction of the ground current is from point A3 to point 1 to east, which is accordance with the potential gradient test. From the different values of 3 points, it can be inferred that SC flows from ground to the pipe somewhere between point A3 and point A2 and discharge from pipeline to ground between point A2 and A1, corrosion may happen.

Protective measures against SCC: All the results getting from test of pipe-soil potential, potential gradient of soil and current within pipeline indicate that the measured gas pipeline is in danger of serious SC interference directly related to the operation of rail transit and protective measures must be carried out.

Protective measures against SCC include reducing leakage from the transit and reinforcement of underground pipelines. For rail transit system, protective measures such as reducing the resistance of rail, installing drainage net, increasing rail-to-ground resistance, ungrounded traction power substations, are widely used. But with the operation of the system, unavoidable contamination, moisture, aging of the insulated orbit will lead to degradation of the stray current protection, SC leakage will increase. So buried metal pipes should take appropriate protective measures against possible stray current interference in vicinity of rail transit system (Cotton *et al*., 2005).

For underground pipeline, methods to modify SCC consist of one or more of the following: installing drainage devices, bonding the interfering and interfered pipeline, strengthening the cathodic protection measures, increasing the distance from the interfering structure, modifying the electrical continuity and increasing the coating resistance of the interfered pipeline. In urban environment, buried metal pipelines and underground structures distributed densely, the SCC protection methods should be chose carefully.

Drainage method, including direct drainage bond, unidirectional drainage bond, forced drainage bond and ground drainage bond, can effectively reduce SC corrosion, but more attention should be paid to avoid secondary interference. Impressed current cathodic protection commonly used in long-distance pipeline system can effectively mitigate SC effects and provide cathodic protection as well, but it also causes secondary interference easily (Park *et al*., 1996).

In downtown areas, where underground pipelines and cables are densely distributed, passive protective measures are mainly used against SCC from rail transit. New pipeline should be located as far as possible from urban rail transit system, since the interference level decreases with distance. The application of coatings to the buried pipeline should be strengthened, through increasing the pipeline to soil resistance to reduce the overall level of stray currents interference. For long steel pipelines located parallel to rail transit, isolating joints should be installed to limit the area exposed to interference. Sacrificial anode protection system, another cathodic protection system commonly used in urban buried pipeline system, can effectively reduce the stray current interference, but it should be strengthened in the environment where SC interference has been proved to exist. All plant and equipment which has been installed to limit the flow of stray current into the electrolyte, or to mitigate its effect, should be inspected and maintained at reasonable intervals.

CONCLUSION

Stray current, arising from the running of DC transit systems, will cause severe localized attack on buried gas pipeline. Dynamically changing intensity and flow direction of SC from rail transit system differ from some traditional sources. In this study, we put forward a system to monitor the stray current, based on Virtual Instrument, automatic and continuous monitoring of stray current can be realized.

With the system, pipe-to-soil potential, potential gradient of soil, current within pipeline of an underground gas pipeline in the neighborhood of rail transit in Shanghai were measured. Results showed that the tested gas pipeline is in danger of serious SC corrosion directly related to the operation of subway.

Protective measures against SCC include reducing leakage from the transit and reinforcement of underground pipelines. For urban gas pipeline, passive protective measures are mainly used. The management of buried gas pipeline and cathodic protection construction and monitoring need to be strengthened in the area with SC.

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