Simulation of Influencing Factors of Buried Pipeline Interfered by Subway Stray Current

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Abstract. The degree of interference of stray currents generated by urban rail transit to nearby buried pipeline was governed by a variety of factors. The buried pipeline model containing the subway return current system was built by COMSOL software, and the fluctuation characteristics of pipeline potential under single and bilateral power supply modes were analyzed to determine the influence of subway return current system parameters and soil resistivity and pipeline corrosion layer resistivity on pipeline potential, while the distribution of pipeline potential under non-uniform soil model was calculated. The results show that when the locomotive traction current and rail longitudinal resistance are doubled, the fluctuation degree of pipeline potential is approximately the same multiple. When the soil resistivity is 1000Ω·m or the pipeline anti-corrosion coating resistivity is 106Ω·m, the pipeline is free from stray current interference. The rail ground transition resistance is not a significant factor of pipeline potential fluctuation. The operation of the train causes the corrosion sate of the pipeline to change constantly. When the longitudinal soil resistivity is unevenly distributed, the increase of soil resistivity at the traction substation side leads to the overall positive shift of pipeline potential and further intensification of pipeline corrosion. The simulation results provide a reference for the railway department and pipeline department in the reasonable planning and layout of rail transit and pipeline.

Keywords: Stray Current; Buried Pipeline; Pipeline Potential; Non-uniform Soil.

1. Introduction

When using the rail as the reflux rail, the urban rail transit is not completely insulated to the ground, and there is current leakage in the actual operation. When the leaked current flows in the soil, it flows into the pipeline due to the low resistance characteristics of the pipeline, and flows out at a distance, causing the electrochemical corrosion of the pipeline[1-3]. In the operation of urban subway, due to the different train frequency, operating conditions and traction strategy, the degree of stray current leakage affecting the buried pipeline is different[4-6]. In reality, the potential value of the pipeline is often determined to determine the interference degree of the buried pipeline during the rail transit operation[7-9]. However, in addition to the subway dynamic interference will affect the degree of pipeline corrosion, some inherent properties from materials and environment also have an impact on it[10-13]. These parameters are usually derived from the field measurement, which has great measurement difficulty and limitations. Due to the limitations of the field environment, it is difficult to analyze a single variable, and the research results are very discrete, which can solve this problem well through computer simulation technology.

In this paper, the fluctuation of the buried pipeline potential caused by the subway stray current, the buried pipeline model including the subway reflux system is built by COMSOL software, analyzes the interference of the buried pipeline potential, and determines the distribution under the heterogeneous soil model.

2. Numerical Simulation of the Pipeline Disturbed by Subway Stray Current

According to the actual subway design, a simulation model including rail, soil, buried pipeline and pipeline anti-corrosion layer is built. In the model, the distance between the two rails is 1.435m, and the specification is 1600×0.1×0.1m, placed in the middle on the upper surface 1600×400×200m, the buried pipe is D720×8mm, according to the upper surface of the soil, the direction is parallel to the rail, the horizontal direction is 10m from the rail, and the pipe anti-corrosion layer thickness is 3mm.

The model is shown in Figure 1. The established model is defined for its material properties, with the specific parameters shown in Table 1. Among them, the rail longitudinal resistance is set by defining the rail resistivity.

The current field of COMSOL software was used for the simulation. There is no subway locomotive and traction substation in the model, and the traction current obtained by the subway locomotive during unilateral and bilateral power supply is compiled by the corresponding rail potential equation in COMSOL and loaded to the upper surface of the rail through the terminal boundary. The rail potential equation is described in ref [14]. In the equation, the substation is at x=0km for unilateral power supply, and the substation is at x=0km and x=1.6km for bilateral power supply.

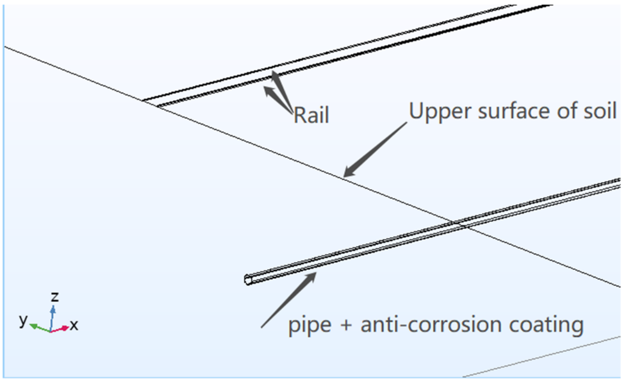


Figure 1. COMSOL Simulation model

In this paper, we only consider the first type of boundary conditions, assuming that the lower surface of the soil is an infinite distance [15]. The contact impedance boundary is added to define the track transition resistance, and the conductivity of the contact impedance is set according to the transition resistance value of the track.

Table 1. Material Attribute Parameters of Simulation Model

Finite element model	Resisttivity / (Ω·m)	relative dielectric constant
rail	1×10^{-7}	1×10^{7}
soil	50	15
pipeline	2.8×10^{-6}	1×10^{7}
Pipeline anti-corrosion layer	5000	6

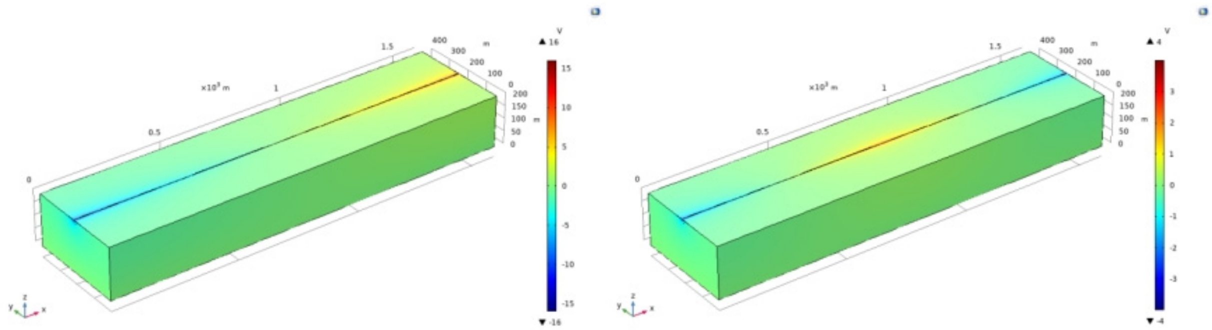
3. Results and Discussion

3.1 Analysis of Single and Bilateral Power Supply Results

In the simulation, the rail longitudinal resistance R_r is 0.02 Ω/km, rail transition resistance R_{rs} is 15 Ω·km, and the longitudinal resistance of the buried pipe is R_s is 0.15 Ω/km, the locomotive traction current I is 1000A, the rail length L is 1.6km, the distance L_1 between the train and the left transformer substation is 1.6 km during unilateral power supply, and L_1 is 0.8km while bilateral power supply. Figure 2 and Figure 3 show the model simulation cloud diagram and the pipeline potential distribution diagram during unilateral and bilateral power supply, respectively.

According to Figure 2 and Figure 3, when other parameters are the same, the rail voltage drop of the unilateral power supply mode reaches 32V, while the rail voltage drop of the bilateral power supply is only 8V, and the rail voltage drop is only 1/4 of that of the unilateral power supply. In the train position, because the rail has the maximum voltage value, the potential of the surrounding soil increases under the influence of the rail voltage, and the voltage gradually decreases when gradually far away from the rail position. The pipeline potential fluctuates under the influence of the rail potential. During the bilateral power supply, the pipeline potential fluctuation is -0.187V~0.180V, and the unilateral power supply is -2.110V~2.141V. Compared with the unilateral power supply, the potential fluctuation of the pipeline is only 8.6%. The bilateral power supply mode significantly reduces the pipeline potential, which causes the pipeline potential to fluctuate by about 25% of the unilateral power supply. The potential fluctuation of the rail in the subway system causes the potential of the surrounding soil area to deviate from the natural state, and the pipeline receives the stray current flowing in the soil due to its low resistance characteristics, and its potential fluctuates accordingly. The fluctuation trend of pipeline potential is the same as that of rail potential. In the train position, the pipeline potential reaches the maximum value and gradually moves negatively to the direction of traction substation, where the pipeline potential is the most negative, and the pipeline potential at the midpoint of train and traction substation is 0.

National standard GB50991-2014 provisions[16]: Without cathodic protection, DC interference is confirmed when the ground potential at any point is offset more than the natural potential by 20 mV. Under the above conditions, whether unilateral or bilateral power supply, buried pipeline are strong interference by the subway system, but the bilateral power supply pipeline interference is significantly less than unilateral power supply, it shows that bilateral power supply is more conducive to the subway system operation and the implementation of pipeline protection, therefore, the railway sector should do traction system monitoring, try to avoid large unilateral power supply way.



(A) Unilateral power supply; (b) bilateral power supply

Figure 2. Cloud map of the potential distribution of the simulation model under single and bilateral power supply

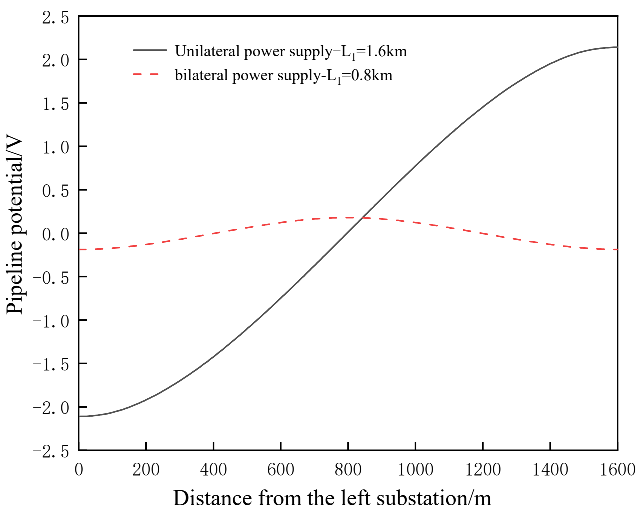


Figure 3. Potential distribution diagram of the pipeline under single and bilateral power supply

Bilateral power supply can be divided into two unilateral power supply sections, and the change trend of a single train-traction substation is the same as that of unilateral power supply. The following is mainly for bilateral power supply analysis[17]

3.2 The Influence of Various Factors under the Bilateral Power Supply

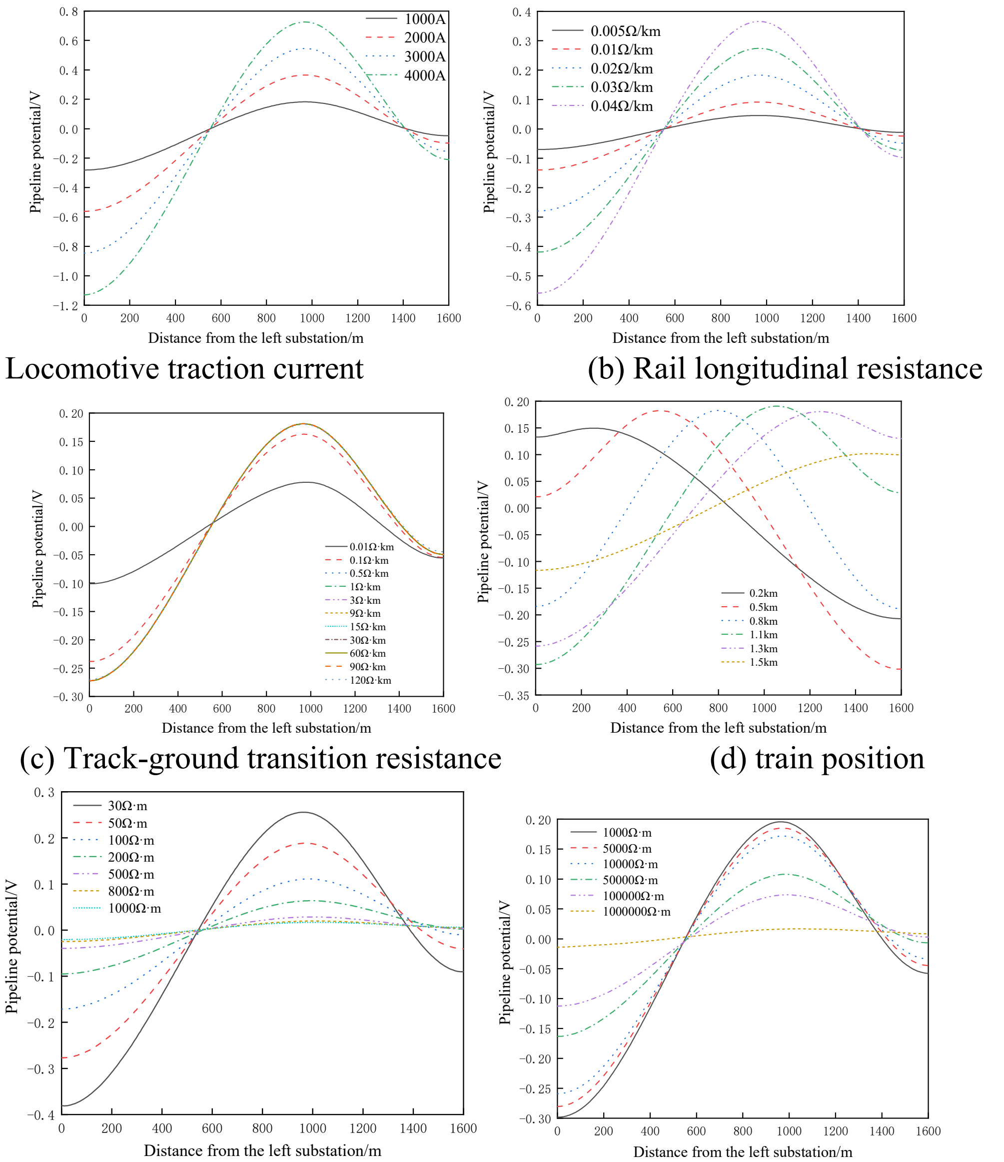
Under the bilateral power supply mode, the train position L_1 is set at 1.0km, analyze the influence of locomotive traction current, rail longitudinal resistance, rail transition resistance, locomotive position, soil resistivity and resistivity of pipeline anticorrosive layer on the potential of pipeline[13,18]. The values of each influencing factor are shown in Table 2. The results are shown in Figure 4.

Figure 4 reflects the influence law of each system parameter on the pipeline potential in the whole model. It can be seen that the locomotive traction current increases from 1000A to 4000A, the pipeline potential fluctuation increases from -0.281V~0.183V to -1.130V~0.725V, and the pipeline potential fluctuation range increases to 4 times the original. The longitudinal resistance of the rail increased from 0.005 Ω/km to 0.04 Ω/km, and the potential fluctuation range of the buried pipeline increased from -0.070V~0.046V to -0.558V~0.366V, and the pipeline potential increased about 8 times the original. It can be seen that when the locomotive traction current and the longitudinal resistance of the rail increase twice, the fluctuation degree of the pipeline potential increases at the same multiple, the increase of the pipeline potential caused by the locomotive traction current is slightly greater than the influence of the longitudinal resistance of the rail. The influence of the rail transition resistance on the potential of the buried pipeline is related to its value, when the transition resistance of the track is less than 0.5 Ω·km, pipeline potential produces large fluctuations with the increase of orbital transition resistance, the pipeline potential fluctuation intervals at 0.01 Ω·km and 0.1 Ω·km are -0.101V~0.0780V and -0.238V~0.163V. However, when the value of the track transition resistance is greater than 0.5 Ω·km, it can be found that the pipeline potential is almost constant in the -0.272V~0.181V interval, this indicates that the change of rail transition resistance does not disturb the pipeline potential greatly. When the position of the train is changed, the position corresponding to the lowest value of the pipeline potential changes, which is always at the substation position on the far side of the train. However, compared with other system parameters, the change of the train position does not have too much impact on the fluctuation range of the pipeline potential. The change of the train location of the pipeline cathode and anode area, in practice, and the rail parallel section of the pipe corrosion distribution in each position, this is because the train has a forward and reverse operation, resulting in the pipeline potential is positive and negative shift, in this case, any position of the pipeline may become the corrosion area of corrosion rupture, in actual engineering, it is difficult to determine the corrosion of the pipeline. When the soil resistivity continues to increase, the fluctuation of the pipeline potential becomes smaller and smaller. When the soil resistivity is 1000 Ω·m, the pipeline potential fluctuation is only -0.020V~0.017V. At this time, the pipeline is almost unaffected by the influence of stray current corrosion. When the resistivity of the pipeline corrosion layer can be taken to 10^6 Ω·m, the pipeline potential fluctuation is only -0.014V~0.017V, at this time, the pipeline is free from stray current interference.

Table 2. Values of the factors that influence the pipeline potential

system parameter	numeric value
Locomotive traction current / A	1000,2000,3000,4000
Rail longitudinal resistance / (Ω/km)	0.005,0.01,0.02,0.03,0.04
Rail ground transition resistance / (Ω·km)	0.01,0.1,0.5,1,3,9,15,30,60,90,120
The distance from the left substation / km	0.2,0.5,0.8,1.1,1.3,1.5
Soil resistivity / (Ω·m)	30,50,100,200,500,800,1000
Resisttivity of pipeline corrosion layer / (Ω·m)	1000,5000,10000,50000,100000,1000000

In the backflow system of the subway, the leakage of the stray electric flow of the rail to the soil depends greatly on the voltage drop of the rail and the transition resistance of the rail. According to ohm's law, locomotive traction current and rail longitudinal resistance is the most important factors affecting the rail potential fluctuation, increase the traction current or rail longitudinal resistance caused rail produce greater pressure drop, in soil resistivity and pipeline anticorrosive layer material under certain circumstances, the pipeline received more stray current, which leads to the increase of the pipeline pressure drop, when the pipeline in this condition, pipeline service life will be greatly shortened. Similar to the rail potential, the rail transition resistance only affects the flow in and out of the equipment, which has a limited impact on the pipeline potential. Soil resistivity and anticorrosive layer resistance determines the ability of the pipeline can receive interference, its directly determines the stray current interference, high soil resistivity represents the soil circulation current ability, pipeline thus reduce the received current interference, the corrosion of the pipeline is reduced, the same, high anticorrosive layer resistivity and the same effect. The change of the running position of the cathode and anode areas of the pipeline potential is not fluctuating, but the pipeline corrosion area is constantly changing.



(a) Locomotive traction current (b) Rail longitudinal resistance

(c) Track-ground transition resistance (d) train position

(e) Soil resistivity (f) pipeline anti-corrosion coating resistivity

Figure 4. Pipeline potential under different influencing factors

During subway operation, attention should be paid to adjust the train operation condition, choose the rail with lower longitudinal resistance, rail insulation setting, ensure the rail near dry clean environment. At the same time, should do pipe insulation protection, choose the anticorrosion layer with higher resistivity, daily construction maintenance should not damage the anticorrosion layer, the pipeline layout chooses soil environment with higher resistivity as the priority of the pipeline.

3.3 Effect of Heterogeneous Soil on Pipeline Potential

During the subway operation, due to the differences in the soil environment along the subway, the soil resistivity varies according to the physical and chemical properties of the soil, which leads to the change of the stray electric flow leaked to the nearby buried pipeline [19-20]. In order to more accurately analyze the interference of subway operation to buried pipelines in the actual environment, the soil was evenly divided into two parts with different resistivity, and the pipeline potential distribution of trains and pipelines passing through different soil environments was simulated. For unilateral power supply, L_1 is taken as 1.6km, and for bilateral power supply, L_1 is taken as 1.0km. Soil resistivity values are shown in Table 3. The simulation results are shown in Figure 5.

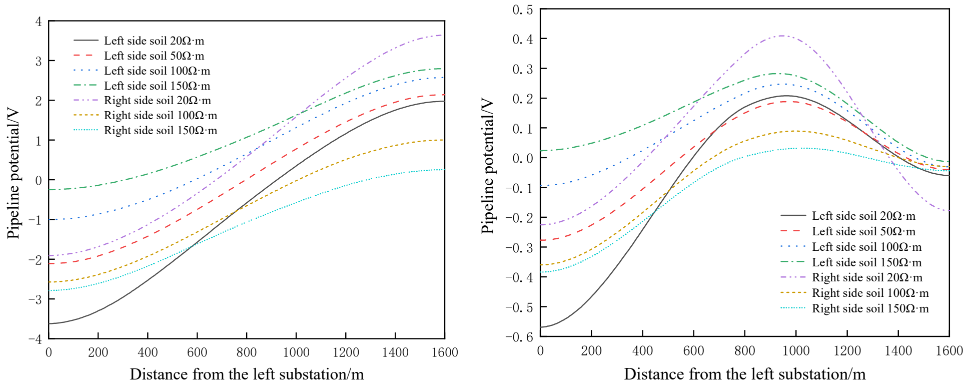
Table 3. Distribution of soil resistivity

	Left side soil (0~0.8km)	Right side soil (0.8km~1.6km)
Resisttivity / (Ω·m)	50	20, 50, 100, 150
	20, 50, 100, 150	50

As can be seen from Figure 5(a): for the unilateral power supply mode, when the left soil resistivity is 20, 50, 100,1 and 50 Ω·m respectively, pipeline potential fluctuations are -3.620V~1.975V, -2.110V~2.141V, -1.000V~2.574V, -0.259V~2.797V, the fluctuation range of pipeline potential is 5.595V, 4.251V, 3.574V and 3.056V respectively, the pipeline potential gradually shifted positively with increasing soil resistance on the left. However, its fluctuation amplitude gradually slows down with the increase of soil resistivity. When the right soil resistivity is 20,50,100 and 150 Ω·m respectively, the pipeline potential is -1.906V~3.636V, -2.110V~2.141V, -2.574V~0.999V, and -2.788V~0.255V, and the pipeline potential fluctuation amplitude is 5.542V, 4.251V, 3.573V and 3.043V respectively, the pipeline potential gradually moves negatively with the increase of the right soil resistivity, but the fluctuation amplitude gradually decreases with the increase of soil resistivity. By analyzing the pipeline potential fluctuation, it can be seen that the pipeline potential fluctuation is the same when the change value in the left soil and the change value in the right soil is equivalent. This may be because when unilateral power supply, only the distribution position of soil resistivity is changed, and the hindering effect on the stray current is the same. The overall voltage drop of pipeline is not affected, but the maximum and minimum values of pipeline potential are related to its distribution position.

As can be seen from Figure 5 (b): when the bilateral power supply mode, When the left soil resistivity is taken at 20, 50, 100, and 150 Ω·m, The maximum value of the pipeline potential is 0.208V, 0.188V, 0.247V, and 0.282V respectively. With the increase of the left soil resistivity, The maximum potential of the pipeline shows a gradual positive shift, the location of the maximum pipeline potential is slightly left with the increase of the left soil resistivity; When the soil resistivity of the right side is 20, 50, 100 and 150 Ω·m, the maximum value of pipeline potential is 0.409V, 0.188V, 0.089V, 0.032V. With the increase of the right side soil resistivity, the maximum potential of the pipeline shows a gradual negative trend, the location of the maximum pipeline potential moves slightly right with the left soil resistivity. Because the train is close to the right traction substation under the simulated power condition, the change of soil resistivity has relatively little impact on the right pipeline potential.

In single and bilateral power supply, the left soil resistance increases, the overall pipeline potential is positive,; the right soil resistance increases, and the overall pipeline potential is negative. The analysis shows that when the soil resistivity on the right side increases, the stray current from the rail leakage to the pipe decreases under the obstruction of high soil resistivity, the fluctuation of the soil potential and pipeline potential caused by the distribution of the rail potential affects the soil resistivity on the left side cannot reduce the current of the rail leakage to the pipe, but will cause the current outflow of the pipe on the pipe difficult, the pipeline potential is further positive, and the pipeline corrosion increases. In practical construction, while taking the pipeline protection measures of low soil resistivity section, the protection of the pipeline potential should be strengthened.



(A) Unilateral power supply; (b) bilateral power supply

Figure 5. Uneven longitudinal soil distribution

In order to further analyze the pipeline potential distribution of trains under uneven soil resistivity, the pipeline potential distribution of different train positions under heterogeneous soil resistivity conditions during bilateral power supply is simulated, and the simulation results are shown in Figure 6.

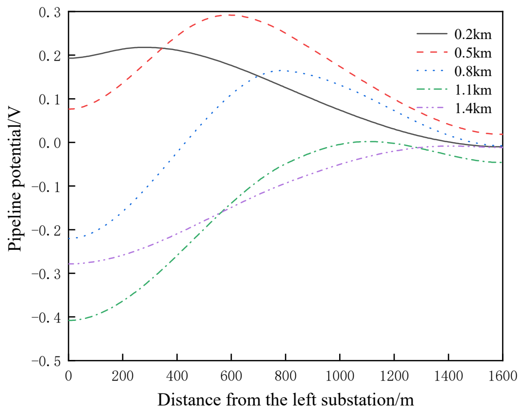


Figure 6. The soil resistivity during bilateral power supply is the pipeline potential of different train positions at 50 Ω·m on the left side and 150 Ω·m on the right side

Figure 6 can be seen that when the soil resistivity is 50 Ω·m on the left and 150 Ω·m on the right, when the train position L_1 is 0.2km, 0.5km, 0.8km, 1.1km and 1.4km respectively, the pipeline potential at the substation at the left end is 0.193V, 0.076V, -0.220V, -0.408V and -0.278V respectively. The pipeline potential shows an overall gradual negative shift trend here. When the train gradually runs from the left traction substation to the right traction substation, the maximum pipeline potential is 0.217V, 0.291V, 0.165V, -0.002V and -0.009V respectively, showing a trend of increasing first and then decreasing. The increase in the right soil resistivity is compared to when the soil resistivity is evenly distributed. It can be seen that the influence of soil resistivity on pipeline potential is greater than the influence of subway dynamic operation parameters, and the reasonable selection of pipeline buried location has a great effect on the buried pipeline from the interference of subway stray current. Therefore, the railway system and pipeline engineering department should take joint measures to ensure the safety of the subway system and pipeline system.

4. Conclusion

(1) Compared with the unilateral power supply, the potential fluctuation of the pipeline is only 8.6% during the bilateral power supply, and the degree of interference of the pipeline is relatively small.

(2) The factors affecting the fluctuation range of pipeline potential are mainly locomotive traction current, rail longitudinal resistance, soil resistivity and resistivity of anti-corrosion layer. When the locomotive traction current and the longitudinal resistance of the rail are doubled, the fluctuation degree of pipeline potential increases by the same multiple; the influence of pipe potential is the change of pipe corrosion area. When the soil resistivity is 1000 Ω·m or the resistivity of the pipeline preservative layer is 10^6 Ω·m, the pipeline is not disturbed by the stray current.

(3) When the longitudinal soil resistivity is evenly distributed, the resistivity of the left soil increases, and the pipeline potential is positive; the right soil resistivity increases, and the pipeline potential is negative. While doing the pipeline protection measures of the low soil resistivity section, attention should be paid to the protection of the pipeline as the anode outflow current part.

(4) When the longitudinal distribution of the soil resistivity is 50 Ω·m on the left and 150 Ω·m on the right, the increase of the soil resistivity on the right leads to the positive deviation of the right pipe potential in the direction no matter where the train runs.

(5) In the construction project, the railway department and the pipeline department should take joint measures to set the location distribution of the track and pipeline, and consider the factors of the nearby soil resistivity. The railway department should plan reasonable subway operation conditions, reduce the longitudinal resistance of the rail as far as possible, and ensure good insulation between the rails. The pipeline department should plan the pipeline construction and corrosion prevention measures to ensure the long-term safe operation of the subway system and the pipeline system.

References

[1] Li Changchun, Li Zhihong, Wang Chen, et al. Study on the corrosion mechanism and influencing factors of DC stray current in buried steel pipe [J]. China's new technology and new products, 2017 (01): 50-51.

[2] Green W K. Steel reinforcement corrosion in concrete - an overview of some fundamentals [J]. Corrosion Engineering Science and Technology, 2020, 55(4), 289-302.

[3] Cao A Lin, Zhu Qingjun, Hou Baorong, et al. Sterse current corrosion and protection of oil and gas pipelines [J]. Gas and Heat, 2009,29 (03), 6-9.

[4] Dong Liang, Yao Zhilin, Ge Caigang, et al. Fourier analysis of the tube ground potential fluctuation characteristics of subway stray current interference [J]. Surface Technology, 2021,50 (02): 294-303.

[5] Cheng Hao. Study on the distribution characteristics and detection of stray current in rail transit [D]. Nanchang: East China Jiaotong University, 2019.

[6] Qin H M, Du Y X, Lu M X , et al.Experimental study on the corrosion behavior of X70 steel under asymmetric dynamic DC interference [J].Materials and Corrosion, 2020,71(11).

[7] Li Gangchuan. Analysis and prevention measures of stray current interference in buried gas transmission pipeline [J]. Total corrosion control, 2021,35 (09), 1-8.

[8] Xiao Song, Jiang Zitao, Tong Qingfu, et al. Fluctuation law of rail transit stray current interference on Wuhan gas pipeline [J]. Corrosion and Protection, 2020,41 (12): 37-43.

[9] Zhu Xiangjian, Du Yanxia, Qin Huimin, et al. Dynamic fluctuation law of ground potential of buried pipeline pipe under the interference of subway stray current [J]. Corrosion and Protection, 2019,40 (12): 878-885.

[10] Fan Meiqi, Sun Yanying, Ma Zhiqiang, et al. Simulation analysis of longitudinal resistance of subway rail [J]. Total corrosion control, 2022,36 (03): 64-68.

[11] Zhu Feng, Li Jiacheng, Zeng Haibo, et al. Effect of urban rail transit ground transition resistance on the distribution characteristics of stray current [J]. High Voltage Technology, 2018,44 (08): 2738-2745.

[12] Charalambous C A. Comprehensive Modeling to Allow Informed Calculation of DC Traction Systems' Stray Current Levels[J]. IEEE Transactions on Vehicular Technology, 2017, 66(11), 9667-9677.

[13] Cao A Lin, Zhu Qingjun, Zhang Shengtao, et al. Simulation study on the influencing factors of stray current in buried metal pipes [J]. Gas and Heat, 2010,30 (05): 6-8.

[14] Guo Zhenhua. Numerical simulation of subway stray current field and its experimental study on the corrosion of steel bar in concrete [D]. Shenzhen: Shenzhen University, 2019.

[15] Fang Jiangmin, Peng Zebiao, Ke Tiantian. Finite element analysis of the cathodic protection potential of buried steel pipes [J]. Petrochemical Equipment Technology, 2016,37 (04), 41-44 + 46.

[16] GB50991-2014. Technical standard for DC interference protection of buried steel pipes [S].

[17] Yan Mingfu, Li Xiaqing, Wang Kuijuan. Research and simulation of subway rail potential and stray current distribution [J]. Journal of Beijing Institute of Petrochemical Technology, 2013,21 (01), 37-41.

[18] Lucca G. Evaluating stray current interference from DC traction lines on a pipeline network by means of a stochastic approach[J]. Electrical Engineering, 2020,103.

[19] Dong Liang, Song Qinfeng, Wu Fang Yun, et al. Effect of environmental media on the corrosion behavior of dynamic DC interference with X80 steel [J]. Corrosion and Protection, 2021,42 (10), 1-7 + 37.

[20] Cao Fangyuan. The influence of soil structure on pipeline leakage current distribution under the interference of Baifeng DC grounding pole current [J]. China Southern Power Grid Technology, 2021,15 (10), 3-11.