International Pipeline Conference — Volume 1
ASME 1996

IPC1996-1850

# EVALUATION OF STRAY CURRENT EFFECT ON THE CATHODIC PROTECTION OF UNDERGROUND PIPELINE

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## ABSTRACT

Two types of stray current which affect the cathodic protection of underground pipeline are discussed. One is the stray current by DC transit system and the other is that originated from the nearby cathodic protection system. The popular evaluation methods of the pipe-to-siol potential measurement was undertaken to evaluate the corrosion activity of pipeline. In case when the pipe was affected by the stray current, the measured pipe-to soil potential was significantly deviated from the mean value resulting in normal distribution. Analysis of such distribution pattern has revealed that the pipe under investigation was in the condition of insufficient protection(noble mean potential and high asymmetry coefficienct) due to the considerable effect of stray current(high standard deviation value). It was also confirmed that the efficiency of drainage system was so low(<10%) due to the improper selection of drainage point. Simultaneous measurement of the magnitude and direction of the sheath current resulted in information about the place where stray current entered into pipe and escaped to soil. For the second case of stray current problem, it is shown that it has been caused by the combined interference from nearby CP system.

## 1. DESCRIPTION OF THE SYSTEM

Seoul area metro is a heavy rail, direct current powered rapid transit system. As of the end of 1995, about 145km is in operation and additional 55km is scheduled to begin operation in early 1996. Figure 1-(a) shows the configuration of the DC rail system 1,500V negative return and natural gas pipeline associated with the case study. Although Seoul area metro system comprises subway, surface and aerial routes, all of the rail systems shown in Figure 1 are subway types. Total length of pipeline under interest is about 20km(from Doksan V/S to Deachi V/S) and it is parallel and/or intersected with 3 different transisit systems of #2, #3 and #4 lines. Along the pipeline there exist 3 valve station(V/S) and 116 test boxes(T/B). It had been protected via sacrificial anodes installed at every 150-200 m and 3 selective drainages.

The separation distance between subway rails and paralleled pipeline is maximum at the right hand side of Bangbae V/S( 2000m) and is minimum at Sillim station and in between T/B 77 and T/B 43. Two electric power sub-stations are located along with both #2 and #3 lines.

Another case study has been carried out on the stray current originated from the cathodic protection system on foreign structure. In Jochiwon area, KGC(Korea Gas Co.) pipeline parallels KOWACO(Korea Water Co.) pipeline for considerable distance and the two lines are intersected and getting far off(Figure 1-(b)). The separation distance between two parallel pipelines is approximately 300m. KOWACO pipeline is protected utilizing rectifier and shallow bed anode which is buried at approximately middle of two pipelines. The point where two line insected is about 1200m away from the anode. It should be noted that this area is free from the nearby train rails since the latter, shown in figure, is not electrified rails.

## 2. STRAY CURRENT FROM TRANSIT SYSTEMS.

### 2.1. Measurement of pipe to soil potential

One of the most common methods to evaluate the effect of stray current on the cathodically protected pipeline is to measure pipe to siol(P/S) potential. Both daytime(transits in service) and nightime(transit off service) P/S potential were measured utilizing $Cu/CuSO_4$ reference electrode. Electrical connection to buried pipe was made through the test wire installed in the test boxes(T/B). P/S potentials were measured and recorded by potential loggers which were designed and fabricated for this study. The logger was small enough(dia.=10cm) and waterproofed so that it can be installed inside test box(dia.=15cm). Triggering the power it starts measuring P/S potential at predetermined time intervals, every 5 seconds for example, and stores potential data for latter analysis. Figure 2 shows potential logger installed inside test box.

P/S potentials before and after transit operation were measured in order to identify the presence of stray current(Figure 3). Stable P/S potential is maintained before the transit operation. Whereas the P/S potential becomes significantly fluctuated after the transit starts operation. The decrease in the P/S potential upon transit operation indicates that the T/B38 is a point where stray current comes into the pipe from soil.

It should be noted that an instantaneous P/S potential value has little meaning when the pipe is under the influence of stray current[10-30]. The presence of dynamically changing stray currents as a superimposed currents to protection current results in a random P/S potential as shown in Figure 4. The evaluation of stray current corrosion activity can be performed by obtaining an asymmetry coefficient($\gamma$), defined as the probability of an event that the potential is more noble than the protection potential(Ep : -850mV vs $Cu/CuSO_4$). Distribution of measured random P/S potential (Figure 4) is shown in Figure 5. It shows a typical normal distribution behavior where the frequency becomes maximum at the mean P/S potential value. Accordingly such random distribution(E(t)) can be analyzed by introducing two components of mean potential($\bar{E}$) and standard deviation(S)

$$\bar{E} = \frac{1}{N}\sum_{0}^{N} E(t) \qquad 1)$$

$$S = \sqrt{\frac{1}{N}\sum_{0}^{N}(E(t) - \bar{E})^2} \qquad 2)$$

The asymmetry coefficient($\gamma$) is defined as

$$\gamma = \frac{N_a}{N} \qquad 3)$$

where :
E(t) : instantaneous P/S potential value
N : total number of readings
Na : number of reading at which E(t) > Ep

The increase in the corrosion activity with increasing $\gamma$ value has been shown by Sokolski and his coworkers[1)-2)].

Result of P/S potential survey in the daytime is summerizing in Table 1. A significant magnitude of standard deviation(230 ~ 500 mV) implies considerable effect of stray current. The mean potential(-300 ~ -770mV) and asymmetry coefficient(0.68 ~ 0.98) indicate insufficient protection.

## 2.2. Measurement of rail to soil and pipe to soil Potentials

Simultaneously measurement of rail to soil (R/S) and P/S potentials provides valuable information on stray current. In case when the current flow from rail to pipe via soil, R/S potential is higher than P/S potential. In other words, rail and pipe behave like anode and cathode, respectively, where current originated from the higher potential anode flows into the lower potential cathode. On the other hand, the relative magnitude of R/S and P/S potentials is reversed when the stray current in the pipe is returned to rail via soil electrolyte.

Result of R/S and P/S potential measurement is shown in Figure 6. Two potentials were measured at the same place(Sillim station) where a selective current drainage system is installed. It is readily seen that the potentials behave in an opposite may. Either one of potentials was not maintained higher than the other indicating current may either come into or flow out the pipe. Moreover. it can be said that, the fact that the P/S potential is not always higher than the R/S potential, the current drainage point was not properly selected.

Lastly the magnitude of R/S potential is worthy of notice. The measured R/S potential of #2 and #3 transit lines was in the range of 30 - 100 volts indicating improper insulation between railways and soil.

## 2.3. Performance evaluation of selective drainage system.

Selective drainage system consists of bonding the pipe to negative rail via some electrical device. This system enables current in the pipe flowing out to the rail while preventing current from flowing into the pipe. Current drain becomes feasible only when the pipe is positive to the rail. As mentioned earlier, there exist 3 selective drainage systems in the area of interest.

The performance of drainage system can be represented by a drainage efficiency which is defined as a ratio between the time in active state(drainage in operation) and that inctive state. Keeping in mind that the selective drainage system becomes active only when the pipe is positive to the rail its efficiency increases with increasing probability of an event that the R/P potential is nagative. Figure 7 shows relationship between R/P and P/S potentials at Sillim station where drainage system is installed. It is shown that the drainage system lowers the P/S potential when the R/P voltage has negative value. It means that current in the pipe is drained to the rail. It should be noted, however, that the probability when the R/P voltage is negative is considerably lower compared to that when the R/P voltage is positive. In other words, the drainage system remains inactive state all most of time thereby lowering its efficiency. The efficiency in this case was as low as 5%. Similar measurements for two other drainage systems shown in Figure 1-(a) has revealed that the efficiency is not greater than 10%. This result implies improper selection of drainage point.

## 2.4. Diagnosis of current flow pattern

Pertinent countermeasures to stray current corrosion can be made when the current flow pattern, such as flow dirention and points of inflow and outflow, is understood. Both the direction and the magnitude of stray current is ditermined by measuring the potential difference between nearby test boxes. Simultaneously measurement of stray current results in current versus current plot as shown in figure 8. The abscissa and ordinate of this plot represent the magnitude of current flowing between nearby test boxes whose separation distance is about 150m. Two measuring point T/B4 and T/B15 are approximately 1600m apart. Current flow from T/B5 to T/B4 and From T/B16 to T/B15 is plotted as positive current while the current flowing in the reverse dirention is plotted as negative current.

Two currents measured between T/B4-5 and T/B15-16(Figure 8-(a)) exhibit a linear relationship whose slope is unit and passing through the origin. This behavior represents that the magnitude of current flowing at T/B15-16 is same as that flowing at T/B4-5. In other words, there is no leaking in or leaking out of current between two measuring points of T/B4 and T/B15. Although a linear relationship is maintained in Figure 8-(b) and Figure 8-(c), the plotting results are lerther suppressed(Figure 8-(b)) or ascended(Figure 8-(c)) with respect to the origin. These behaviors imply that the magnitude of current at two measuring points is different while maintaining current direction. In other words, there exist leaking in point(s) in between T/B38 and T/B43(Figure 8-(c)) and leaking out point(s) in between T/B59 and T/B77(Figure 8-(c)). Results of current flow pattern analysis are rerequisite information when remedial action is to be undertaken.

## 3. STRAY CURRENT FROM OTHER CP SYSTEMS.

### 3.1. Diagnosis of Interference

The second case involves two underground pipelines at Jochiwon area. As described earlier, two pipelines of KGC and KOWACO parallel each other with separation distance of approximately 300m(refer to Figure 1-(b)). Reportedly the P/S potential at T/B15 of KGC pipeline is so low(-6,000mV ~ -8000mV) that it may experience over-protection problem. On site investigation has revealed the presence of CP system of KOWACO whose shallow bed anode is located at approximately the middle of two pipelines. As a result, the reported P/S potential was thought as a result of anode interference. The effect of KOWACO's CP system on KGC pipeline was investigated. P/S potentials at various points on KGC pipeline were measured depending on the condition of KOWACO's CP system( Table 2). At the T/B15, the nearest test box from CP anode, a significant difference in the P/S potential( 4.2volt_ was observed depending on the ON and OFF condition of CP system. Anodic interference, where protection current originated from the CP-anode is unintentionally flow into KGC pipeline, is responsible for the observed P/S potential behavior at test box 14 and 15. It is worthwhile to note the opposed behavior of P/S potential at the crossing point. Contrary to the P/S potential behavior at test box 14 and 15, that at the crossing point increased when CP system is ON condition. This represent a cathodic interference. As a conclusion, it can be said that the KGC line is under influence of combined interference from KOWACO's CP system.

### 3.2. Remedial action

Counteractions against stray current due to interference can be taken in several ways. The best way is to cut down the leakage current from CP-anode. Installation of insulation barrier between anode and pipe has been proved as a good example. Another possibility is to install steel plate between anode and pipe. In this case the steel plate is electrically connected to the rectifier so that the collected leakage current is returned to the rectifier. Installing barrier or plate, however, is frequently infeasible in practice due to wide area. The remaining possibility, adopted in this study was to disperse the leakage-in from the anode. This is done by electrically connecting the pipe and the steel structure of nearby bridge. The measured P/S potential at T/B15 after electrical connection was increased from -6.32 V to -3.7 V indicating significant decrease in leakage-in current to the pipe.

Another action was taken at the crossing point where cathodic interference had been observed. Two pipelines of KGC and KOWACO were connected via impedance bonding of 1Ω. The measured P/S potential were -1.15 V and -1.05 V for pipes of KGC and KOWACO, respectively.

## REFERENCE


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2) Sokolski, W., 1987, "Computer analysis of stray current corrosion activity on pipelines," B. Electrochem. Vol. 3, pp. 643-647.
3) Juchniewicz, R., and Sokolski, W., 1985, "Field evaluation of a new method to determine stray current corrosion activity," Materials Performance, Vol. 24, pp. 26 -28.
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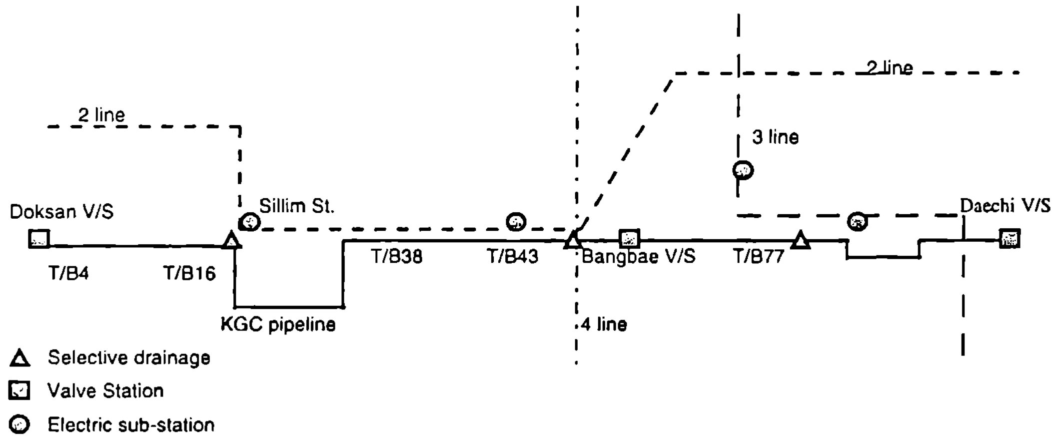
**Table 1. List of Mean Value and Standard Deviation of P/S Potential in the daytime**

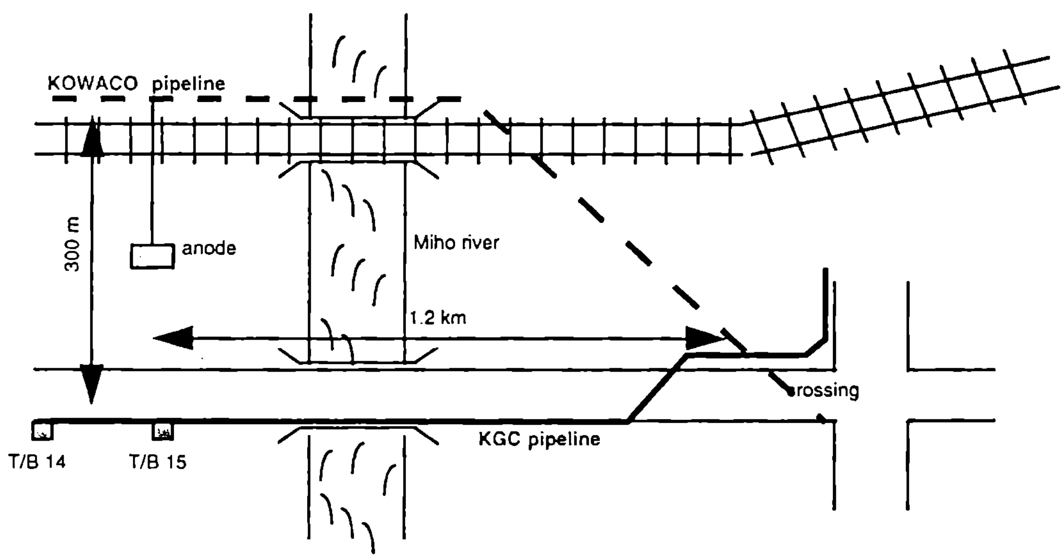
| | T/B27 | T/B37 | T/B59 | T/B69 | T/B93 |
|---|---|---|---|---|---|
| E(mV) | -360 | -293 | -336 | -769 | -578 |
| S | 234 | 497 | 491 | 235 | 481 |
| γ | 0.98 | 0.87 | 0.87 | 0.68 | 0.71 |

**Table. 2. Pipe to soil potential of KGC pipeline depending on the condition of CP system of KOWACO pipeline**

| condition \ position | T/B14 | T/B15 | crossing point |
|---|---|---|---|
| KOWACO's CP System ON | -4.24V | -6.32V | -0.68V |
| KOWACO's CP System OFF | -1.77V | -2.17V | -1.3V |




(a) Seoul area




(b) Jochiwon area

**Fig. 1. Schematic description of two areas under investigation.**
**(a) Seoul area - stray current from DC transit system.**
**(b) Jochiwon area - stray current from CP system.**

Fig. 2. Photograph of potential logger installed inside test box

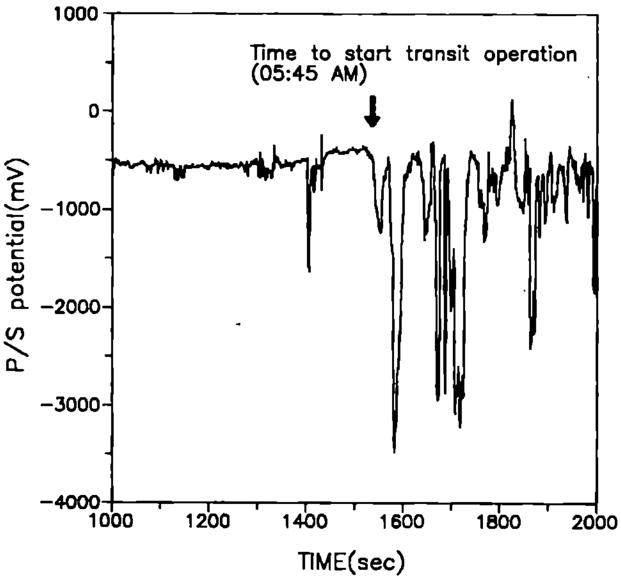



Fig. 3. P/S potential vs time profile at T/B38.

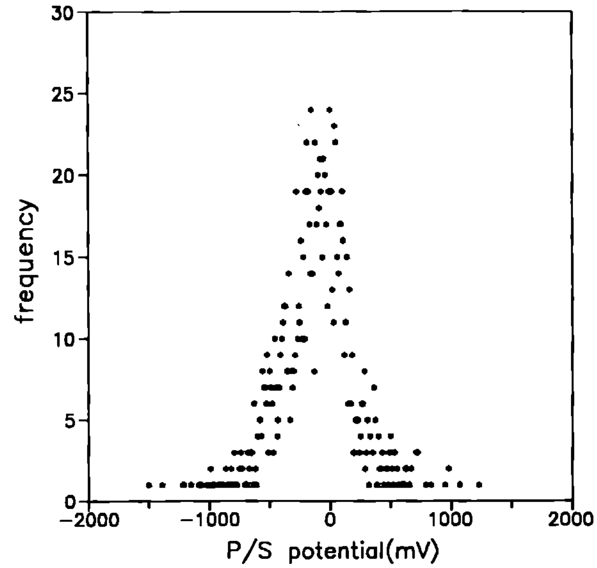



Fig. 5. Distribution of P/S potential data at T/B.

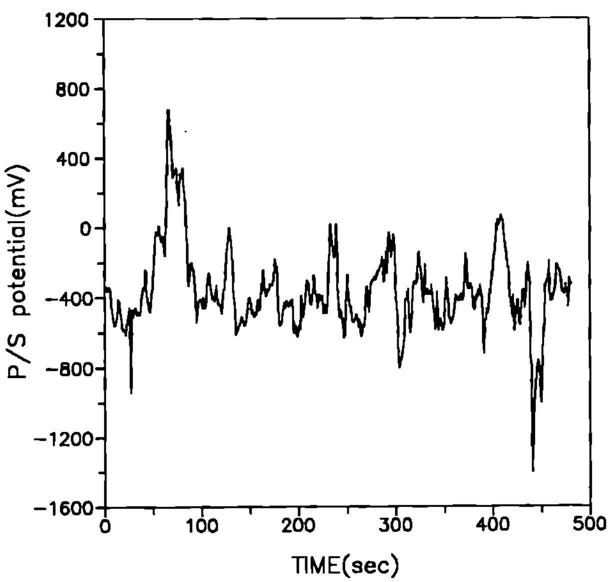



Fig. 4. P/S potential variation in the daytime.

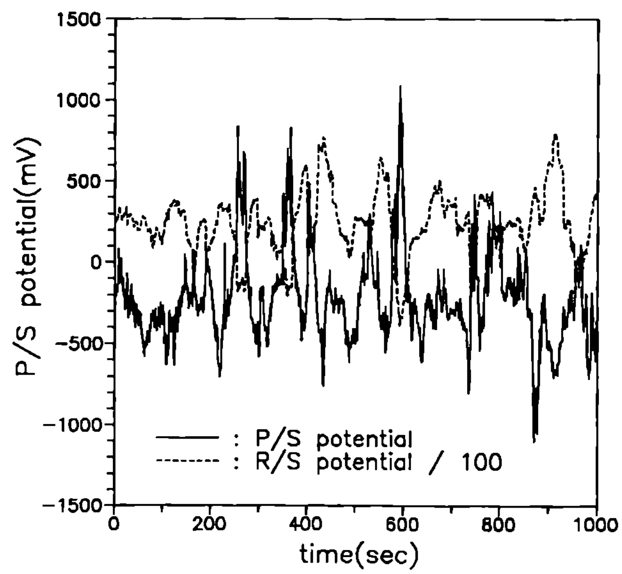



Fig. 6. Comparision between P/S potential at Sillim station.

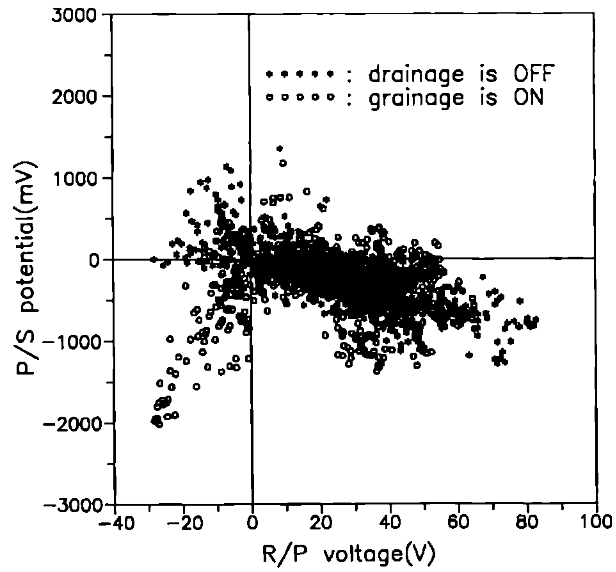



Fig. 7. P/S potential vs R/P voltage at Sillim station.

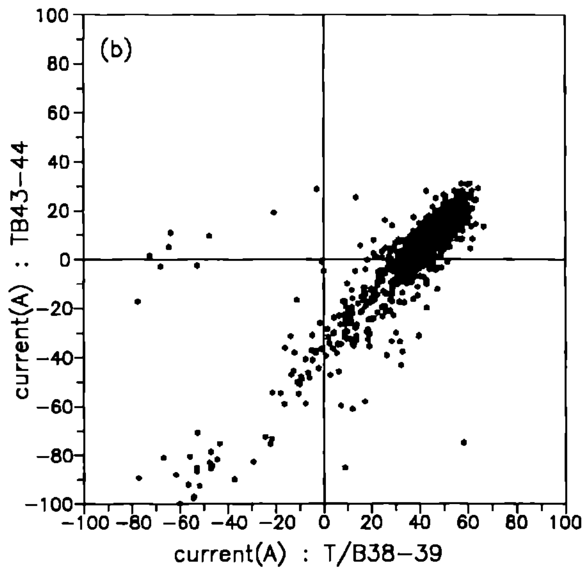



Fig. 8-b). The magnitude and the direction of current along the pipeline.

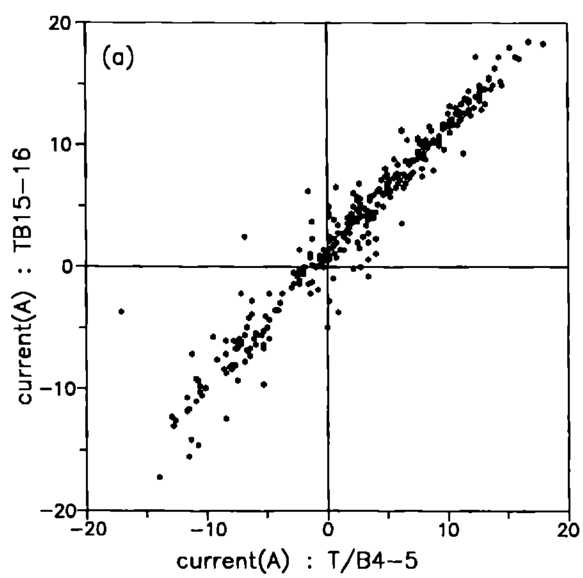



Fig. 8-a). The magnitude and the direction of current along the pipeline.

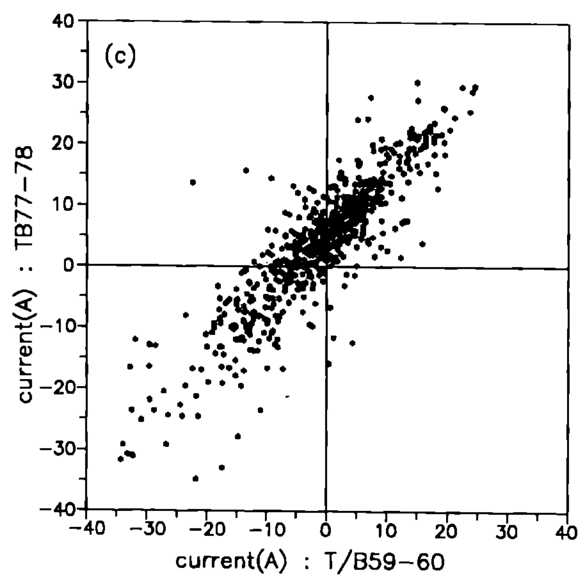



Fig. 8-c). The magnitude and the direction of current along the pipeline.