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A CAN-Based Urea Line Heater Diagnostics Development and Experimental Validation for Selective Catalytic Reduction (SCR) System

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ABSTRACT Urea line heating system is critical for Selective Catalytic Reduction (SCR) aftertreatment system under low temperature environment. Traditionally, the Electronic Control Unit (ECU) motivates urea lines heating command and diagnostics directly. This paper illustrates a Controller Area Network (CAN)-based line heater architecture development for the SCR aftertreatment system, as well as the diagnostics generation. The CAN-based line heater diagnostics is validated on vehicle experimental with four different given cases. It can be seen from the validation results that the diagnostics logic and algorithm are reasonable, and the line heater failure modes could be detected correctly including open circuit, short circuit and inducement. In addition, the failure modes are able to set or clear for each of the urea lines according to the diagnostics logic. ECU and ECU1 could communicate well between each other by CAN. This study introduces a new line heater architecture for SCR aftertreatment system which is meaningful for the whole vehicle assembly, which could be considered in the real application in future.

INDEX TERMS Line heater, aftertreatment system, diagnostics.

I. INTRODUCTION

SCR system is demonstrated as an effective way to reduce nitrogen oxides (NOx) emission for diesel engine system and this technique is widely used so as to meet more and more critical emission regulations on NOx emission requirements. The urea would be injected into mixer with exhaust gas when SCR catalyst bed temperature is at the appropriate value under the certain duty cycle condition, to guarantee the best NOx conversion efficiency for lower NOx emission.

It has been seen that urea decomposition would be affected by temperature. And there are several researches that consider solutions to deposit issue under low temperature. Börnhorst, Chen, and Li *et al.* showed the effect to urea decomposition by temperature, which was a very critical factor on deposit issue of SCR system [1]–[4]. Zhang, Scott Sluder and Tang *et al.* undertook urea decomposition under low temperature, as well as the effects on SCR performance [5]–[7]. Lecompte and Ning *et al.* used dosing control strategy to manage urea injection to achieve high NOx reduction efficiency [8], [9]. Okada *et al.* selected a urea reforming method including a heat resource, so as to consider further improvement of NOx reduction at a low temperature [10]. Sadashiva *et al.* studied the model to benefit dosage strategy at low temperature for SCR system [11]. Wang and Lecompte *et al.* researched specific catalyst performance by ice melting method under the low temperature SCR [12], [13]. Zhao *et al.* introduced a solution to reduce deposit of SCR system at low temperature [14]–[16]. There are many researchers who have made efforts to study solutions on heating system for SCR aftertreatment system, so as to make sure normal working status under low temperature such as engine cold start. Stephan emphasized the importance of urea tank thermal engineering on melting and freezing behavior of the urea [17]. Choi *et al.* analyzed the capability of heating and melting system for urea tank, which system is circulated by engine coolant [18]. El-Sharkawy *et al.* applied thermal analysis on the urea tank solution warm up for SCR system under low ambient temperature, and described heating system process for melting the frozen urea [19].

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Those researches indicate that it is important for urea system heating under low temperature for normal SCR system working and required NOx reduction efficiency.

Generally, the urea solution with a concentration of 32.5% is adopted in the SCR system. When the ambient temperature is extremely low, the urea would be frozen in the urea circulation system and the injector would be stuck to inject urea into mixer. The system backpressure would increase due to SCR system blockage, which affects the NOx emission as there would be no reactions with urea or even affects the normal working capability of engine. It introduces a urea heating function into SCR system to avoid this issue under extremely low temperature, and the heating command is controlled by ECU. On many applications, there is only one ECU to collect sensors singles and send commands to actuators on engine as well as the whole vehicle related parts. For some applications, there is another ECU on vehicle which would need to take the urea lines architecture into consideration for effective functions.

The purpose of this study is to develop a CAN-based line heater architecture for the SCR aftertreatment system, as well as to generate the urea lines diagnostics. In this study, four cases are designed to validate the CAN-based line heater diagnostics on a 6-cylinder diesel engine which is installed on the vehicle. The diagnostics results are discussed to analyze the logic and algorithm for urea lines open circuit failure, short circuit failure and inducement failure. In addition, this study introduces a new line heater architecture for the SCR aftertreatment system which is meaningful for the whole vehicle assembly. That could be considered in the real applications in future. In summary, this study introduces contributions as below,

1) A CAN-based line heater diagnostic is established;

2) The algorithm for the CAN-based line heater diagnostic is validated;

3) A new line heater diagnostics strategy for the SCR system is created;

4) Another line heater diagnostics strategy besides on traditional strategy is provided.

II. MATERIALS AND METHODS

A. PRINCIPLE

Figure 1 shows urea circulation system including urea lines integrated with line heater. Urea tank and urea supply are heated by engine coolant. The urea lines use electronic heating which heaters are integrated with urea lines. There are three urea lines in the system, which are suction line, pressure line and drain line. Suction line is used to introduce urea from tank into urea supply. The pressure line is between urea supply and urea injection, and it is to introduce the urea which is pumped from urea supply into urea injector. The urea is injected to the mixer with specific ANR to achieve the best NOx conversion efficiency of the SCR aftertreatment system at a certain condition. The urea which is not reacted will drain back to urea tank through the drain line.

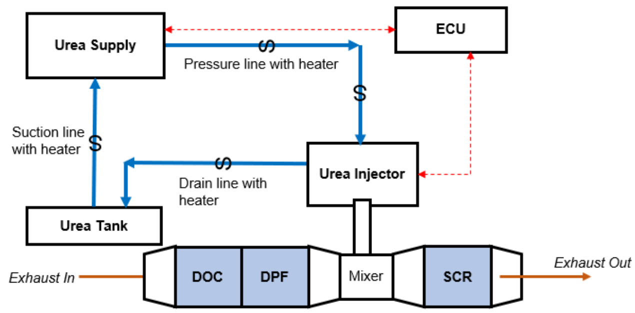


FIGURE 1. Urea circulation system with line heater.

The urea pyrolysis mechanism and droplet evaporation include a series of complex reactions. The urea droplets would begin to evaporate with rising temperature after being gradually heated by exhaust gas from engine to the whole aftertreatment system. As the water starts to evaporate from the aqueous urea solution at the earliest point in time due to its lower boiling point, urea can be directly pyrolyzed from the solid or liquid phase. In a word, the urea droplets are heated up and water evaporates first, followed by the thermolysis of urea into ammonia and isocyanic acid [20]:

$$(NH_2)_2CO(aq) \rightarrow (NH_2)_2CO(l) + H_2O(g) \quad (1)$$

$$(NH_2)_2CO(l) \rightarrow NH_3(g) + HNCO(g) \quad (2)$$

The urea inside urea injector could cool the injector, so that the injector can stay healthy in mechanical even when exhaust gas temperature is high in some certain conditions. When the ambient temperature is extremely low, the urea will transfer to deposit in the whole circulation system, including urea lines, urea tank, urea supply and urea injector. The deposit will block the system and result in higher system backpressure which affects NOx emission. Under such condition, the urea needs heating to guarantee the urea system can work normally. The urea tank and urea supply can be heated by engine coolant, while urea lines use electrical heating. Generally, the heater is integrated with urea line. When ECU sends out heating command to the system, the relays between ECU and urea lines will active heaters and the three urea lines would be in heating status. If there are failures of urea lines, the ECU would collect urea lines status and detect directly to enable related fault code accordingly.

In some applications, there is another ECU on vehicle which is already integrated relays inside it. There will be information communication by CAN between these two ECUs, while the urea circulation system would be similar. Considering this kind of vehicle arrangement, it develops a CAN-based line heater architecture and diagnostics in this study. In one hand, it could remove the relays between ECU and urea lines to optimize vehicle arrangement integration. And in the other hand, it could improve the communications between the two ECUs.

B. CAN-BASED LINE HEATER ESTABLISHMENT AND DIAGNOSTICS DEVELOPMENT

Figure 2 shows the architecture for urea line heater when there is only one ECU for the whole vehicle system. The ECU manages all line heater related functions, such as heating command control, line heater diagnostics and so on. The line heater signal is sent to ECU directly. When ECU decides to send out heating command by related input information judgement, the heating command will enable and active the relays to heat urea lines.

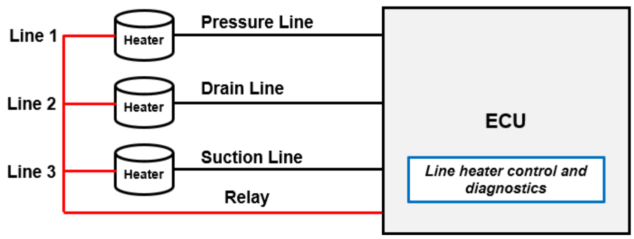


FIGURE 2. Urea line architecture with one ECU.

Figure 3 shows the architecture for urea line heater when there is another ECU on vehicle. ECU1 is the one on vehicle, and there are relays integrated inside ECU1 so that the relay in Figure 2 can be removed, which could make the arrangement much easier. There is data communication interface between ECU and ECU1. Line heating command will be analyzed by ECU and sent to ECU1 by CAN. ECU1 manages line heater control after getting the line heating command. ECU1 also collects urea lines status and shares with ECU by CAN. Then ECU manages the line heater diagnostics based the inputs. It can be seen the line heater diagnostics would be different between urea lines architecture with one ECU and with two ECUs.

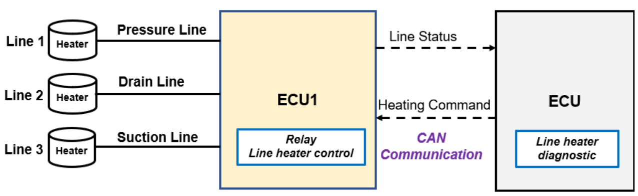


FIGURE 3. Urea line architecture with two ECUs.

In this experimental, urea lines are described in Table 1. It establishes the CAN-based line heater diagnostics in this study, which is mainly based on urea line architecture with two ECUs.

TABLE 1. Urea lines description.

Line	Line Description
Line1	Pressure Line and Heater
Line2	Drain Line and Heater
Line3	Suction Line and Heater

There are three urea lines which are considered in this urea injection system for NOx conversion. It defines three status for each urea line, that is short circuit status, open circuit status and normal status. ECU1 checks the urea lines status and communicates with ECU by CAN. Table 2 defines the urea lines status statement. When a urea line is in short circuit, it will announce 4 for the line status during diagnostics. And when urea line is in open circuit, line status will show 5. If the urea line is in normal status, 31 will be sent out to describe line status.

TABLE 2. Urea lines status statement.

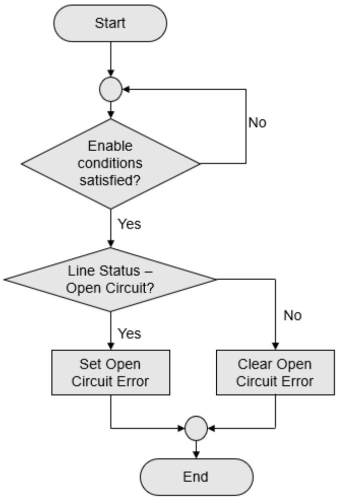
Line Status	*Status Definition*
Short Circuit	4
Open Circuit	5
Normal	31

Table 3 describes diagnostics statement for urea lines. Totally 7 fault codes are introduced in urea lines diagnostics group, including the open circuit and short circuit for each line, as well as the inducement diagnostics. Fault Code11, Fault Code21 and Fault Code31 stand for open circuit status of Line1, Line2 and Line3. Fault Code12, Fault Code22 and Fault Code32 stand for short circuit status of Line1, Line2 and Line3. As the heating is important for urea defrost during the extremely low temperature environment, it is required the engine to actuate given action to protect the whole system if there are failures on urea lines when the ambient temperature is low. As a result, the inducement diagnostics is considered and requires engine torque derate when urea lines failures under the real low ambient temperature. Fault Code4 is defined for inducement diagnostics.

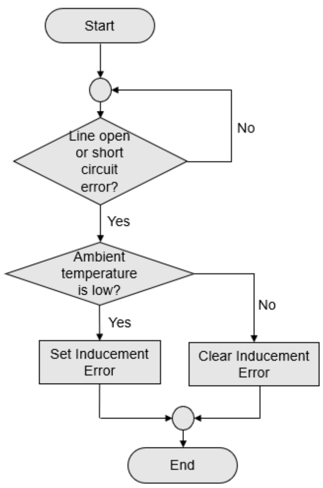
TABLE 3. Diagnostics statement for urea lines.

FAILURE MODE	LINE1	LINE2	LINE3
Open Circuit	Fault Code11	Fault Code21	Fault Code31
Short Circuit	Fault Code12	Fault Code22	Fault Code32
Inducement Fault	Fault Code4		

Figure 4.1 shows the open circuit judgement flow chart. The open circuit diagnostics related faults codes, including Fault Code11, Fault Code21 and Fault Code31, follow this judgement flow chart to set or clear. Take Fault Code11 as example, the ECU would firstly check if all the conditions are satisfied to enable open circuit fault code. When the Line1 is in open circuit, Line1 status would show the status as 5 to ECU by ECU1 through CAN communication. The diagnostics enables Fault Code11 accordingly, otherwise, Fault Code11 will not be triggered. To clear Fault Code11, the Line1 status needs to be on 31 which means Line1 should be recovered in normal status. The short circuit diagnostics flow chart is designed as the similar as the open circuit



4.1. Open Circuit Diagnostics Flow Chart



4.2. Inducement Diagnostics Flow Chart

FIGURE 4. **Diagnostics flow chart.**

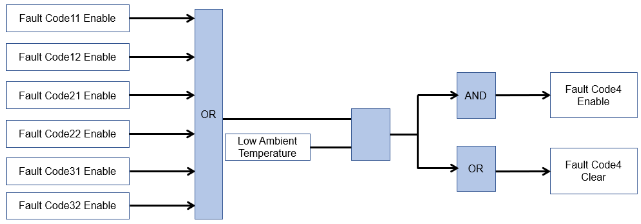


FIGURE 5. **Inducement diagnostics algorithm.**

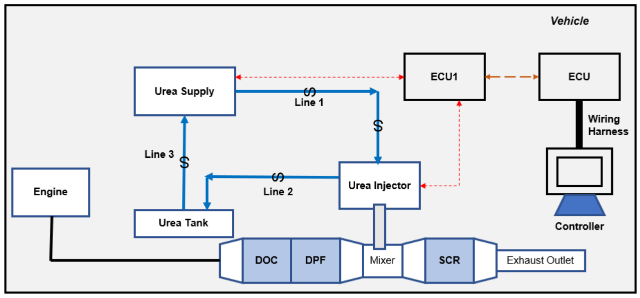


FIGURE 6. **Experimental layout on vehicle.**

diagnostics flow chart. Fault Code12, Fault Code22 and Fault Code32 follow this flow chart.

Figure 4.2 shows the inducement diagnostics flow chart. There are two key elements for inducement diagnostics, one is to check if there is open circuit or short circuit of any of Line1, Line2 or Line3, the other is the ambient temperature judgement. It uses Matlab Simulink to establish line heater diagnostics algorithm. Figure 5 shows the inducement diagnostics algorithm.

C. DIAGNOSTICS VALIDATION ON VEHICLE

1) TEST SET-UP

Figure 6 shows the experimental layout on vehicle with the CAN-based line heater diagnostics related equipment arrangement. This vehicle is powered by a 6-cylinder diesel engine, with the DOC+DPF+SCR aftertreatment system installed on the chassis of vehicle. The engine exhaust flow enters into aftertreatment system and then finally goes out through the aftertreatment exhaust outlet after a series of reactions in the system to achieve NOx emission requirements. The exhaust gas from exhaust outlet goes into the air via vehicle tailpipe. Urea injector is mounted with mixer which is one part of the aftertreatment system. Urea supply and urea tank are installed on vehicle. The three urea lines are used to connect corresponding parts in urea circulation system. Line1 is the urea pressure line with heater, which connects urea supply and urea injector. Line2 is the urea drain line with heater, which is between urea injector and urea tank to drain back urea into tank. Line3 is the urea suction line with heater, which is used to supply urea from tank into urea supply. ECU1 transfers information to control the actuators in urea circulation system and ECU1 is installed on vehicle. ECU is integrated on engine and it uses CAN to communicate line heater control and diagnostics information.

In order to simulate the cases to validate CAN-based urea line heater diagnostics development algorithm, a controller is connected with ECU through an electrical wiring harness. This controller could set parameters value as required and collect diagnostics validation results. The main parameters that need to set would be heating command, ambient temperature, and so on. The lines conditions are set by manually. During the test, the operator will disconnect the lines to monitor open circuit and short the lines to monitor short circuit. The ambient temperature input is set through controller for inducement diagnostics validation.

2) EXPERIMENTAL CASES DESIGN

Four cases are designed to validate the CAN-based urea line heater diagnostics. The cases are considered based on the algorithm of urea lines open circuit diagnostics, short circuit diagnostics and inducement diagnostics. The detailed cases design is described in Table 4. It designs fours cases

TABLE 4. Cases description on vehicle validation.

CASE	DESCRIPTION
Case1	Simulate open circuit fault code for Line1 and Line2, as well as the related inducement fault.
Case2	Simulate open circuit fault code for Line1, Line2 and Line3.
Case3	Simulate open circuit fault code & short circuit fault code for Line1 and Line2, as well as the related inducement fault.
Case4	Simulate open circuit fault code & short circuit fault code for Line1 and Line3, as well as the related inducement fault.

to validate the diagnostics on vehicle with real urea lines conditions. Case1 is to monitor the open circuit status of urea pressure line (Line1) and urea drain line (Line2) to validate Fault Code11 and Fault Code21 diagnostics. In addition, it controls the ambient temperature command by controller to simulate the ambient temperature status, and then to check Fault Code4 diagnostics. Case2 is to simulate the open circuit status of the three urea lines and recover the lines status to normal, so as to validate diagnostics logic of Fault Code11, Fault Code21 and Fault Code31 at the same time. Case3 is to monitor the different urea lines status of pressure line (Line1) and drain line (Line2), then to validate the diagnostics logic of Fault Code11, Fault Code12, Fault Code21, Fault Code22 and Fault Code4. Case4 is to monitor the different urea lines status of pressure line (Line1) and suction line (Line3), then to validate the diagnostics logic of Fault Code11, Fault Code12, Fault Code31, Fault Code32 and Fault Code4.

These four cases are representative to simulate the lines status and validate the diagnostics of open circuit, short circuit and inducement. In the real experimental on vehicle, it suggests at least two persons to operate together to make sure the cases could be simulated well. One is to monitor urea lines status in each case designed, while the other is to manage the controller.

III. RESULTS AND DISCUSSIONS

This CAN-based urea line heater diagnostics provides a new option for line heating system when there are two ECUs, one ECU on engine and the other on vehicle. Compared to existing line heater diagnostics, line heater diagnostics in this study uses CAN communication to transfer related information about urea lines. It establishes an algorithm model based on CAN for line heating system, which is regarded as a new compared to traditional heating system strategy. In order to validate the diagnostics in this CAN-based line heater system, four cases are simulated on vehicle to monitor different conditions. The comprehensive experimental results are showed in this part to validate the CAN-based urea line heater diagnostics algorithm, as well to check the CAN communication.

A. TEST RESULTS WITH CASE1

Figure 7 shows the three urea lines status in Case1. The urea pressure line (Line1) status announces 5 which means it is in open circuit all through the test time and the suction line (Line3) is kept in normal status (31). Drain line (Line2) is in normal status (31) at the beginning, and the status is changed to open circuit (5) at about 320s. That is to monitor drain line (Line2) failure mode with open circuit. The three urea lines status could match the description in Case1.

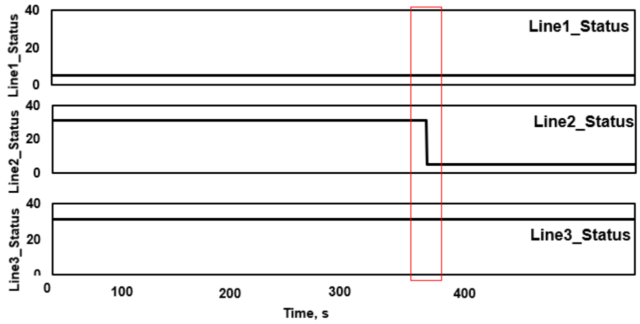


FIGURE 7. Urea lines status in Case1.

Figure 8 shows urea pressure line (Line1) open circuit diagnostics validation in Case1. With the open circuit status of pressure line (Line1), Fault Code11 is triggered correctly. And Fault Code11 is still active as the pressure line (Line1) is not recovered to normal status.

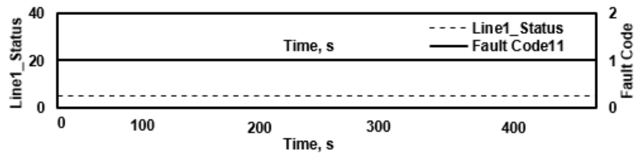


FIGURE 8. Urea Line1 open circuit diagnostics validation in Case1.

Figure 9 indicates urea drain line (Line2) open circuit diagnostics validation in Case1. When Line2 status is in normal status (31), Fault Code21 is not triggered. And when Line2 status changes to open circuit (5), Fault Code21 becomes active. From Figure 8 and Figure 9, it can be found that Fault Code11 for Line1 and Fault Code21 for Line2 could be triggered independently according to the diagnostics algorithm.

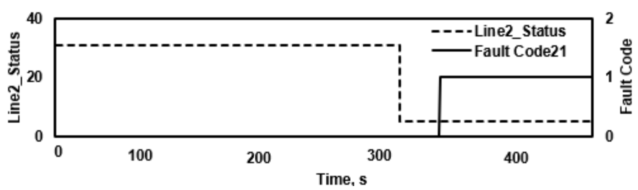


FIGURE 9. Urea Line2 open circuit diagnostics validation in Case 1.

Figure 10 shows inducement diagnostics validation in Case1. As the pressure line (Line1) is in open circuit status through all the test time, it needs to simulate ambient temperature to check inducement diagnostics. It sets the ambient temperature input (Ambient_Air_Temp) by the controller to monitor the inducement diagnostics validation.

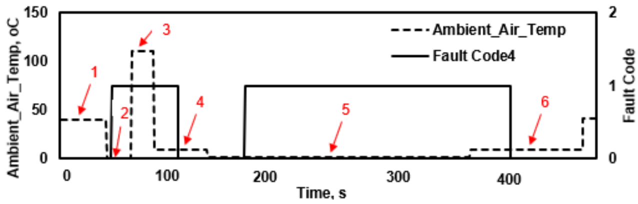


FIGURE 10. Inducement diagnostics validation in Case1.

1) In the first 40s, the ambient temperature is set around 40°C, Fault Code4 is not triggered.

2) It sets the ambient temperature to nearly 0°C about 40s, which temperature is regarded as low. And the inducement fault code (Fault Code4) is triggered.

3) The ambient temperature is set to extremely high which is about 110°C at 60s. It can be found that Fault Code4 is still active. That is because the ambient temperature is in unreasonable range, which would be not able to clear the inducement fault code. This could match the inducement diagnostics logic.

4) Then at 90s, the ambient temperature is set to normal range (10°C), and Fault Code4 is clear.

5) At 140s, the ambient temperature is set to low again to about 0°C, the inducement diagnostics is triggered again and the Fault Code4 is active accordingly.

6) It sets the ambient temperature to 10°C again at 370s, and Fault Code4 is clear as the ambient temperature is not regarded as low under this condition.

The experimental results show successful diagnostics validation in Case1. The open circuit fault codes of pressure line (Line1) and drain line (Line) could be triggered based on the related logic. As well, the inducement diagnostic could perform correctly according to the algorithm.

B. TEST RESULTS WITH CASE2

Figure 11 shows urea pressure line (Line1) open circuit diagnostics validation in Case2. With the urea pressure line (Line1) status changes, the related open circuit fault code is set or clear.

1) When the urea pressure line (Line1) is in normal status (31), Fault Code11 is inactive in the beginning. After the operator disconnects the urea pressure line, it indicates Line1 status to 5 from 31. Then the open circuit fault code (Fault Code11) is active.

2) At about 360s, the operator connects the urea pressure line and the Line1 status is recovered to normal status (31) from open circuit status (5). The related open circuit fault code (Fault Code11) is clear.

3) The operator disconnects the urea pressure line again at about 700s, then Line1 status changes to 5 from 31. It can be seen that Line1 status could be announced correctly with the real line status. As a result, the open circuit fault code (Fault Code11) comes up.

4) At 820s, the operator recovers the pressure line (Line1) to normal and the related open circuit fault code is clear.

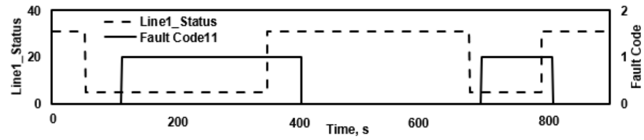


FIGURE 11. Urea Line1 open circuit diagnostics validation in Case2.

Figure 12 shows urea drain line (Line2) open circuit diagnostics validation in Case2, while Figure 13 shows urea suction line (Line3) open circuit diagnostics validation in Case2. It can be found the same open circuit diagnostics logic for Line2 and Line3 as that in Figure 11 for Line1. The urea lines status could match the description in Case2. With the operator disconnects the urea lines, the line status can be announced to ECU1 correctly. And the open circuit diagnostic algorithm is validated successfully for Line1, Line2 and Line3. In addition, Fault Code11, Fault Code21 and Fault Code31 could be set or clear independently, which would help to detect urea line heater open circuit failure quickly.

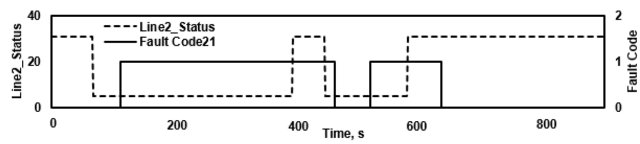


FIGURE 12. Urea Line2 open circuit diagnostics validation in Case2.

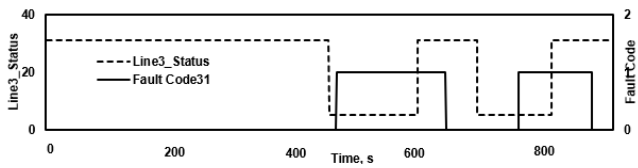


FIGURE 13. Urea Line3 open circuit diagnostics validation in Case2.

C. TEST RESULTS WITH CASE3

Figure 14 shows urea pressure line (Line1) open circuit and short circuit diagnostics validation in Case3.

1) The urea pressure line (Line1) is in open circuit status (5) in the beginning, Fault Code11 is active and Fault Code12 is inactive.

2) At about 60s, the operator monitors short circuit of the urea pressure line (Line1). The Line1 status changes from 5 to 4. Under this condition, the short circuit fault code of Line1 (Fault Code12) comes up. At the same time, the open circuit fault code of Line1 (Fault Code 11) is still active, as Fault Code11 could not be clear if Line1 status is not as 31.

3) At 470s, the operator recovers the urea pressure line (Line1) to normal status. The Line1 status indicates as 31 from 4. Then Fault Code11 and Fault Code12 are clear.

Figure 15 shows urea drain line (Line2) open circuit and short circuit diagnostics validation in Case3. It can be found the same open circuit and short circuit diagnostics logic for Line2 as that in Figure 14 for Line1.

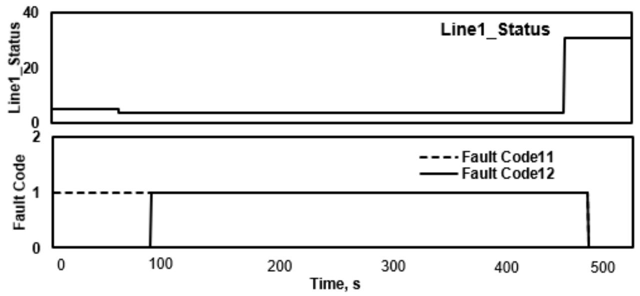


FIGURE 14. Urea Line1 open circuit and short circuit diagnostics validation in Case3.

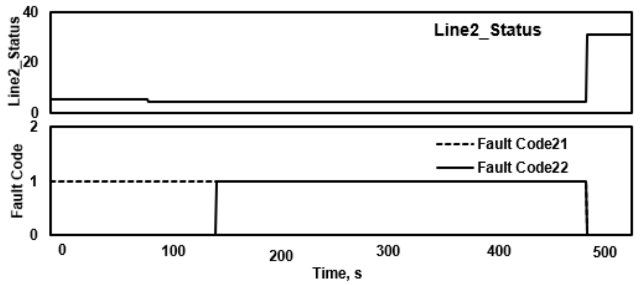


FIGURE 15. Urea Line2 open circuit and short circuit diagnostics validation in Case3.

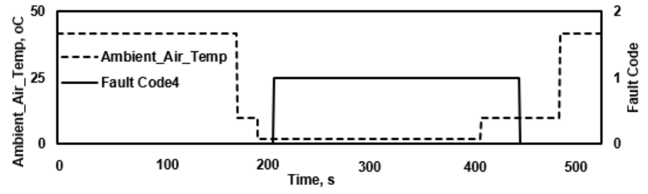


FIGURE 16. Inducement diagnostics validation in Case3.

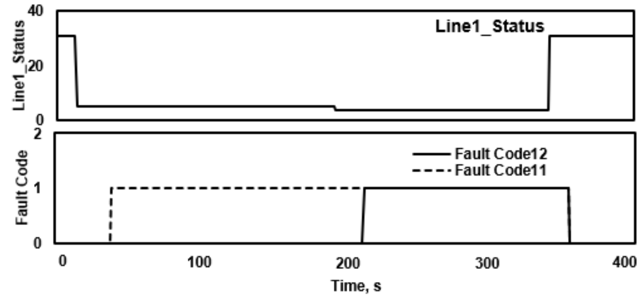


FIGURE 17. Urea Line1 open circuit and short circuit diagnostics validation in Case4.

Figure 16 shows inducement diagnostics validation in Case3. From 0s to 470s, the open circuit fault code for Line1 (Fault Code11) and Line2 (Fault Code21) are still active, it sets the ambient temperature input (Ambient_Air_Temp) in controller to monitor the inducement diagnostics validation.

1) In the first 170s, the ambient temperature is set around 40°C, Fault Code4 is not triggered.

2) It sets the ambient temperature to about 10°C at 170s, Fault Code4 is not triggered.

3) At 200s, the ambient temperature is set to low to about 0°C, the inducement diagnostics is triggered and the Fault Code4 is active accordingly.

4) It sets the ambient temperature to 10°C again at 420s, and Fault Code4 is clear as the ambient temperature is not regarded as low under this condition.

The urea lines status could match the requirements in Case3. With the operator monitors different urea lines status, the lines status can be announced to ECU1 correctly. And the open circuit diagnostic algorithm is validated successfully for Line1 and Line2. The short circuit diagnostic algorithm is validated successfully for Line1 and Line2 as well. In addition, the inducement diagnostic could perform correctly according to the algorithm. The experimental shows successful diagnostic validation in Case3.

D. TEST RESULTS WITH CASE4

Figure 17 shows urea pressure line (Line1) open circuit and short circuit diagnostics validation in Case4.

1) The urea pressure line (Line1) is in normal status (31) in the beginning, Fault Code11 and Fault Code12 are inactive.

2) At about 20s, the operator monitors open circuit of the urea pressure line (Line1). The Line1 status changes from 31 to 5 and Fault Code11 becomes active.

3) About 200s, the urea pressure line (Line1) status is monitored as short circuit. And Line1 status changes to 4 from 5. Under this condition, the short circuit fault code of Line1 (Fault Code12) comes up. At the same time, the open circuit fault code of Line1 (Fault Code 11) is still active, as Fault Code11 could not be clear if Line1 status is not as 31.

4) At 350s, the operator recovers the urea pressure line to normal status. The Line1 status indicates from 4 to 31. Then Fault Code11 and Fault Code12 are clear.

Figure 18 shows urea suction line (Line3) open circuit and short circuit diagnostics validation in Case4. It can be found the same open circuit and short circuit diagnostics logic for Line3 as that in Figure 17 for Line1.

Figure 19 shows inducement diagnostics validation in Case3. From 20s to 350s, the open circuit fault code for Line1 (Fault Code11) and Line3 (Fault Code31) are still active, it sets the ambient temperature input (Ambient_Air_Temp) in controller to monitor the inducement diagnostics validation during this period.

1) Fault Code4 is not triggered when the ambient temperature is above 10°C.

2) At 120s, the ambient temperature is set to low to about 0°C, the inducement diagnostics is triggered and the Fault Code4 is active accordingly.

3) It sets the ambient temperature to 40°C at 350s, and Fault Code4 is clear.

The urea lines status could match the requirements in Case4. With the operator monitors different urea lines status, the lines status can be announced to ECU1 correctly. And the open circuit diagnostic algorithm is validated successfully for

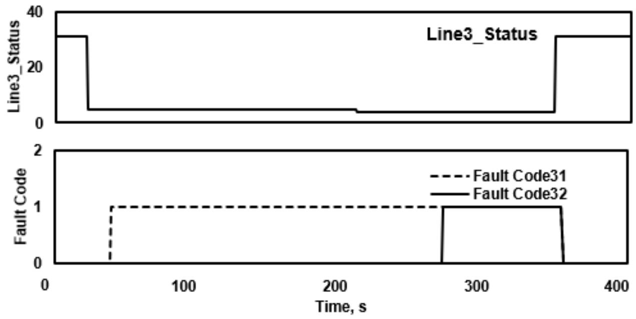


FIGURE 18. Urea Line3 open circuit and short circuit diagnostics validation in Case4.

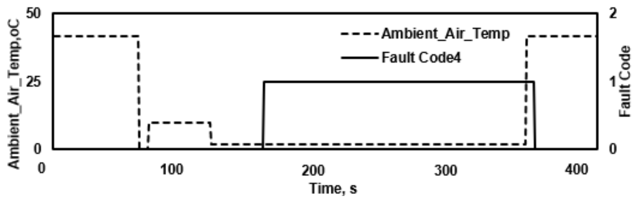


FIGURE 19. Inducement diagnostics validation in Case4.

Line1 and Line3. The short circuit diagnostic algorithm is validated successfully for Line1 and Line3 as well. In addition, the inducement diagnostic could perform correctly according to the algorithm. The experimental shows successful diagnostic validation in Case4.

E. BENCH TEST RESULTS COMPARISON TO VEHICLE TEST RESULTS WITH CASE2

The line heater diagnostics validation is conducted on vehicle directly to monitor the failures in real applications, so that the validation results could be more credible. The CAN-based line heater diagnostic is considered to test on bench which uses signal setting to simulate urea lines status before validating on vehicle, so as to understand the feasibility for the algorithm of the CAN-based line heater diagnostics. Those four designed cases are validated on bench, and the results show consistent for the CAN-based line heater diagnostics. This part is to show the diagnostics validation test results on bench under Case2, and to compare the results on vehicle under Case2 to check test methods effectiveness.

Figure 20 shows urea lines open circuit diagnostics validation in Case2. With the urea lines status change, the related fault code is active or inactive based on the open circuit algorithm. Take Line1 (urea pressure line) as an example,

1) When the urea pressure line (Line1) is in normal status (31), Fault Code11 is inactive in the beginning. After setting the urea line status to 5 from 31, Line1 open circuit fault code (Fault Code11) is triggered.

2) At about 480s, it sets the Line1 status from 5 to 31. That is to change Line1 from "open circuit" to "normal status". The related open circuit fault code (Fault Code11) is clear.

From the figure above, Fault Code21 and Fault Code31 could be detect correctly based on the algorithm.

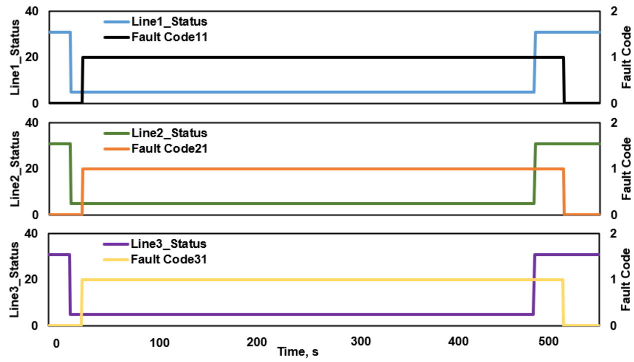


FIGURE 20. Urea lines open circuit diagnostics validation on bench in Case2.

The open circuit fault code for each urea lines could be reported and clear according to the open circuit logic, and it is independently to detect Fault Code11, Fault Code21 and Fault Code31. Compared to the test results in Case2 on vehicle, the test results on bench could show the consistent conclusion for the CAN-based line heater diagnostics.

IV. CONCLUSION

The CAN-based line heater architecture is established in the study and the related diagnostics development is successful validated with different cases in vehicle experimental. From the study and experimental results, it can be validated as below –

1) The open circuit diagnostics logic and algorithm are successfully established for the CAN-based urea lines, including urea pressure line, urea suction line and urea drain line.

2) The short circuit diagnostics logic and algorithm are successfully established for the CAN-based urea lines, including urea pressure line, urea suction line and urea drain line.

3) The lines status can be showed correctly with lines status, which proves the information communication is effective.

4) The inducement diagnostic logic is successfully development.

When there is another ECU on vehicle, the CAN-based line heater architecture is proposed to apply. It is meaningful for the whole vehicle arrangement as this CAN-based line heater architecture will remove relays for the urea lines and be easier to install on vehicle. In addition, it would improve the interaction between two ECUs by CAN communication. In further when consider it into real application, it suggests diagnostics validation in real low ambient environment.

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