LNG선 Boil-off Gas 재액화장치의 동적거동에 관한 연구

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The Study of Dynamics of Boil-off Gas Re-liquefaction System of LNG Carrier

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1. Introduction

LNG is usually transported by LNG carrier, and BOG occurs when LNG is transported by LNG carrier because of heat ingress into cargo tanks. BOG increases the pressure of cargo tanks, which means safety problems could happen. Therefore BOG must be removed from cargo tanks for safety. At the present time, BOG is used as the fuel for LNG carrier.

Recently, the system re-liquefying BOG has been studied. Before making the actual system, dynamic simulation must be performed for many reasons. In this paper, dynamic simulation is performed to confirm dynamics of each case of round trip by using Aspen HYSYS.

2 Dynamic Simulation

2.1 Condition of Each Case

A case is classified by the operation sequence of LNG carrier. Figure 1 shows the operation sequence of LNG carrier. Based on the operation sequence, there are 7 cases. Table 1 shows the BOG condition of each case of round trip in the LNG carrier.

Case A-1 corresponds to the laden mode, and case A-5 corresponds to the excessive mode. Case A-2 and A-3 are imaginary cases and do not exist. Case A-4 is the case of high-N_2 content on the laden mode. Case B-1 and B-2 correspond to the ballast mode.

2.2 Process Description

The cold BOG from cargo tanks is warmed up exchanging heat from the warm BOG from the aftercooler of the BOG compressor at the BOG exchanger. Then two three-stage BOG compressors compress the warm BOG. After compression, each aftercooler removes the heat caused by compression. The compressed BOG is cooled down to the cryogenic temperature by exchanging heat to the cold BOG from the cargo tanks at BOG the exchanger. Then the BOG is

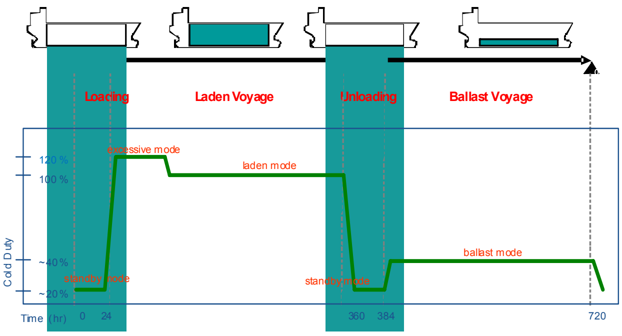

Figure 1 The Operation Sequence of LNG Carrier

Table 1 The BOG Condition of Each Case

Case	Composition, mole%				Flow Rate, kg/h	Temperature, ℃
	Nitrogen (N_2)	Methane (C1)	Ethane (C2)	Propane+ (C3+)		
A-1	16.97	83.02	0.01	0.00	7023	-109
A-2	8.53	91.46	0.01	0.00	5738	-100
A-3	0.00	100.00	0.00	0.00	6138	-108
A-4	32.99	67.00	0.01	0.00	8298	-110
A-5	13.57	86.72	0.01	0.00	9776	-106
B-1	14.94	85.05	0.01	0.00	3006	-38
B-2	12.80	87.19	0.01	0.00	507	-10

condensed at the cold box which consists of the brazed aluminum plate fin heat exchanger.
Two nitrogen companders are installed. The compander consists of a three-stage nitrogen compressor and a nitrogen expander. Nitrogen used as refrigerant is compressed at the nitrogen compressor. The compressed nitrogen is firstly cooled down at the cryogenic heat exchanger and then expanded at the expander. The expanded nitrogen condenses the BOG and warms up itself at the cold box, i.e., the cryogenic heat exchanger.
One nitrogen tank is installed to supply nitrogen to the nitrogen cycle or to withdraw nitrogen from the nitrogen cycle. When BOG load increases up, nitrogen is injected from the nitrogen tank to the nitrogen cycle. When BOG load decreases down, nitrogen is withdrawn from the nitrogen cycle to the nitrogen tank. Figure 2 represents the PFD of the BOG re-liquefaction system.

2.3 Dynamic Simulation

2.3.1 Open Loop Test

To control the system, a cascade control strategy is used. The inner loop test is carried out in such a way that the opening of the nitrogen injection valve and the nitrogen withdraw valve are changed in a step line manner. +1% represents that the nitrogen

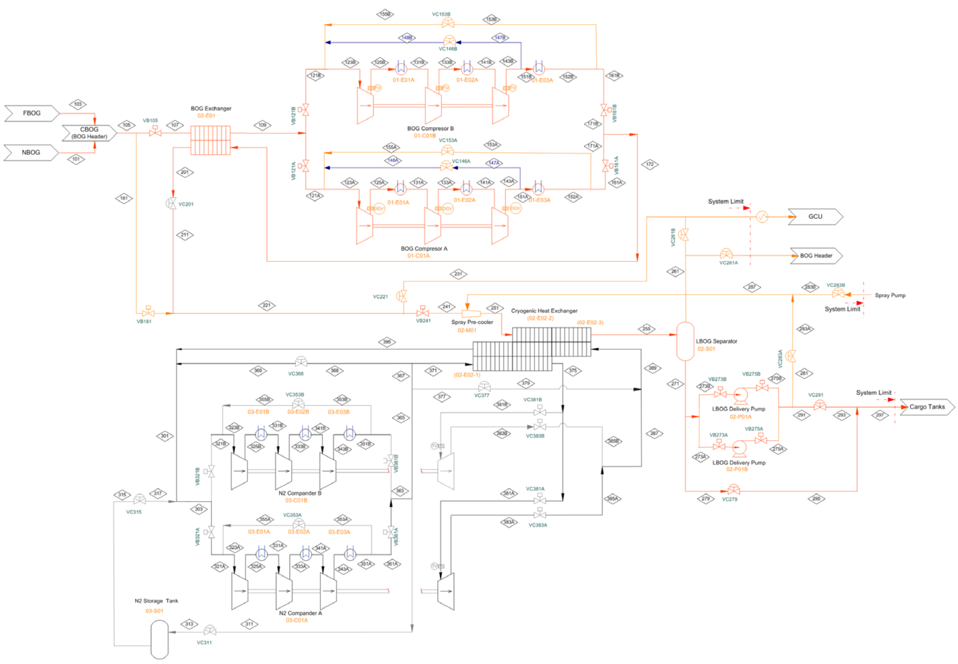

Figure 2 The PFD of the BOG Re-liquefaction System

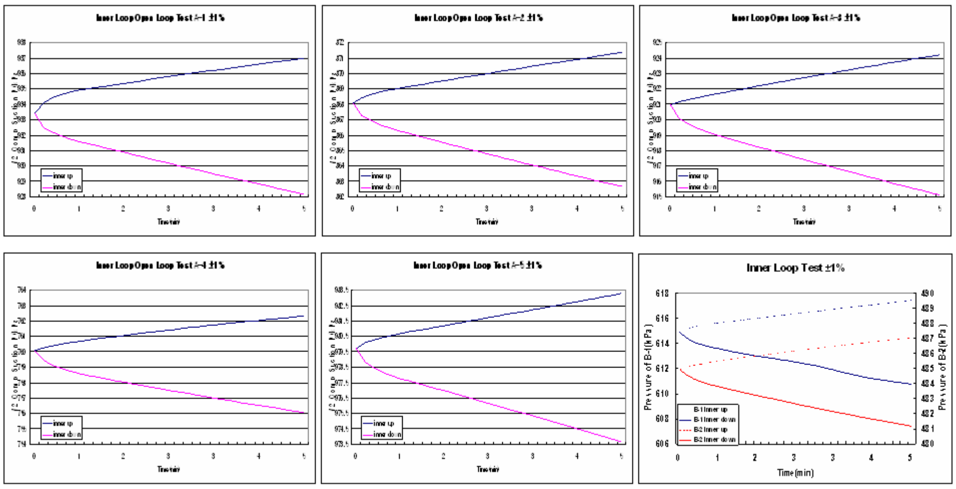

Figure 4 Inner Loop Test

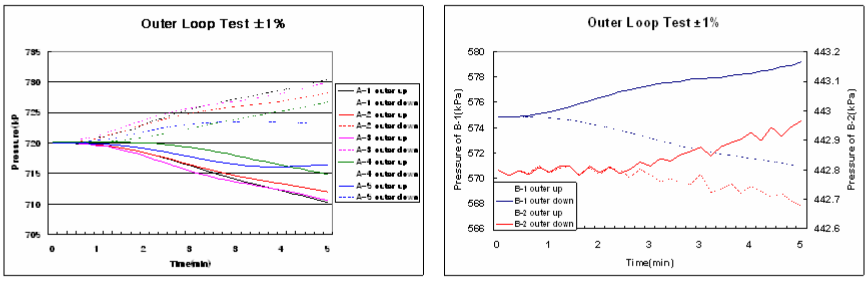

Figure 5 Outer Loop Test

injection valve is open by 1%, and -1% represents that the nitrogen withdraw valve is open by 1%. The outer loop test is carried out in such a way that the pressure of the nitrogen compressor is increased/decreased by 1%. As it can be seen, the figure 4 and 5 show that output response is quite different from each other for each case. It means the system has a strong nonlinearity through a round trip.

2.3.2 Disturbance Rejection Test

As it is mentioned above, the operating range of the system is wide, which means the

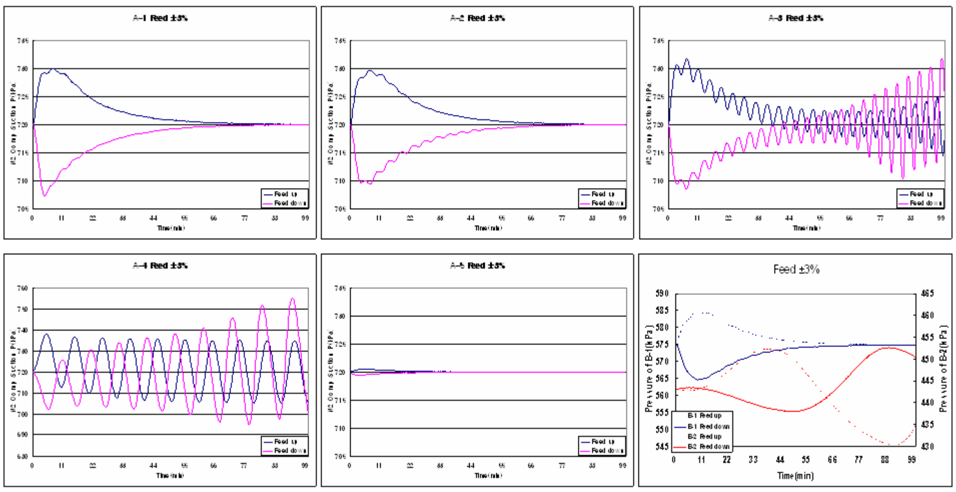

Figure 6 Disturbance Rejection Test 1

Master Kc : 0.31, Ti : 20 Slave Kc : 7.461, Ti : 0.1166

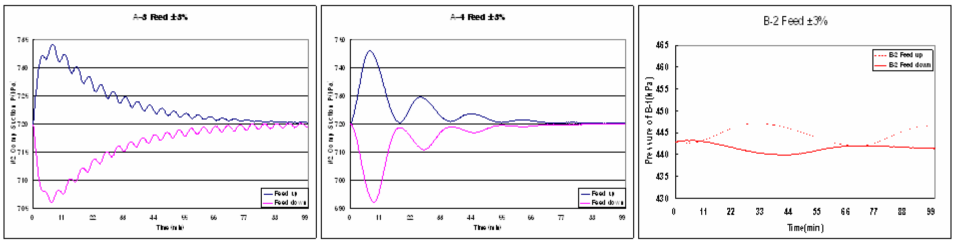

Figure 7 Disturbance Rejection Test 2

Table 2 Controller Parameters used for Disturbance Rejection Test 2

	Master			Slave		
	Kc	Ti	Td	Kc	Ti	Td
A-3	0.25	25	0	6.717	0.1174	0
A-4	0.15	22	0	7.862	0.1240	0
B-2	0.65	200	5	9.598	0.1171	0

parameters of controllers should be changed from case to case. Therefore disturbance rejection test is performed to confirm control performance and to check whether same controller parameters can be used for each case or not. As a result of disturbance rejection test, it is confirmed that controller parameters must be reset case by case.

3. Conclusions

Dynamics of boil-off gas re-liquefaction system of LNG carrier is studied. It is confirmed that the controller parameters must be reset case by case to cope with the strong nonlinearity due to the wide operating range. To deal with this nonlinearity, the advanced control strategy such as a gain scheduling must be required. Furthermore, in order to secure the linearity of inner loop, the pressure of the nitrogen storage tank must be maintained at the center between the suction and discharge pressures of the nitrogen compressor.

Acknowledgment

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