# Correlation between fuel rack sticking and unintentional re-starting of EDG

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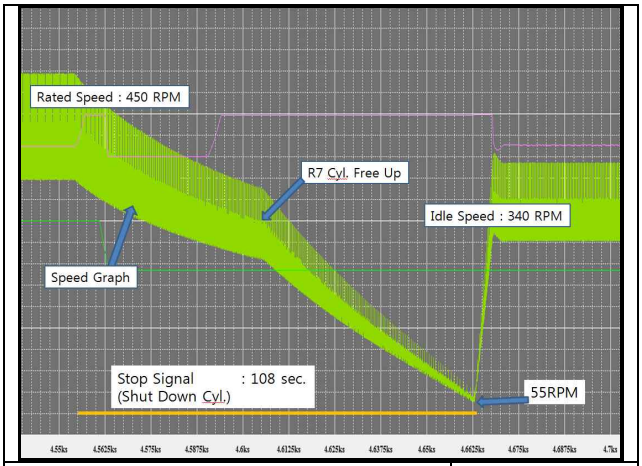
## 1. Introduction

The Emergency Diesel Generator (EDG) was being tested after overhaul maintenance. While the EDG was running at the rated speed (450 rpm), an operator pressed the manual stop button. But the EDG failed to stop and unintentionally started again. After the unintentional re-start, the EDG maintained running speed of 340 rpm. (Fig. 1)

In the category of a governing system, this paper analyzes the cause of unintentional restart of the EDG that unintentionally re-started and maintained a speed at 340 rpm. The results of the analysis were then verified by a test run. Finally, we identified a correlation between fuel rack sticking and unintentional re-starting of the EDG




| | |
|---|---|
| Engine(Type/Manufacturer) | DSRV-16-4 /COOPER |
| Rated Speed | 450 rpm |
| The minimum Speed before re-starting | 55 rpm |
| The time of the decreasing speed | 108 Sec. |
| The speed after re-starting | 340 rpm |

Fig. 1. Auto Restart

## 2. Methods and Results

A recorder was used for EDG motion signal acquisition and analysis. Simulation equipment (Portable Speed Loop Tester, 8909-555) supplied by Woodward was used to simulate the EDG operating conditions.

### *2.1 Composition of Governing System*

In fig. 2 & 3, the governing system is composed of an electric governor, a DRU (Digital Reference Unit), a mechanical governor, fuel linkages, and fuel injection pumps. The governing system adjusts the amount of fuel supplied to the combustion chamber (cylinder) and thus controls the rotational speed of the EDG. If a stop signal is generated, the shutdown cylinder interrupts the fuel discharged from the fuel pump to stop the EDG.

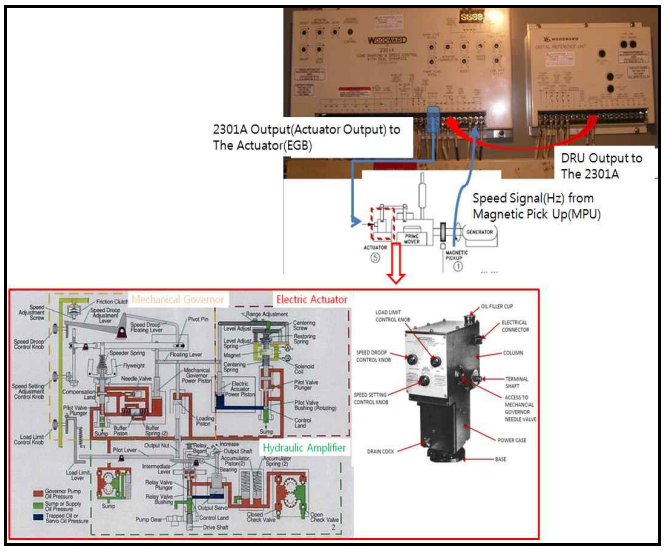



Fig. 2. Governing System(Electrical – Mechanical)

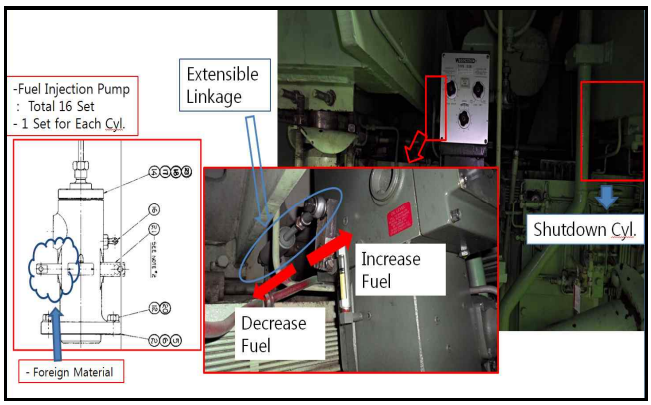



Fig. 3. Governing System(Mechanical-Linkage-Fuel Injection Pump, Shutdown Cylinder)

### *2.2 Logic Signal*

Fig. 4 shows the logic circuit of the EDG. Because the manual stop signal is a self return type, it is temporarily applied only and disappears when the manual stop button is un-pressed. When the stop signal is applied, the shutdown cylinder immediately blocks the fuel from being discharged from the fuel injection pump and makes the EDG stop. The time during which

the shutdown cylinder blocks the fuel is determined by the sum of the time of charging and discharging the accumulator (⑥).[1] In accordance with the graph (Fig. 1), the shutdown cylinder had blocked the fuel for about 108 seconds.

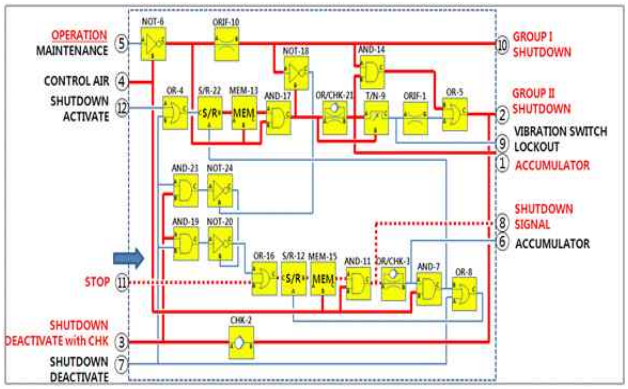



Fig. 4. Stop Signal Logic

*2.3 Electric Governor Signal*

The electric governor output (Actuator Output) signal is the lowest (0Vdc) during returning the rotational speed, which decreases immediately after the stop signal was applied, to the set value[1]. The final target value of the governing system is determined by the sum of the electric governor output target value and the DRU output. Immediately after the stop signal occurred, the DRU output was maintained at 0Vdc and the target value of the governing system was maintained at the rated rotational speed (450 rpm) of the EDG. 6.5 seconds after the stop signal was applied, the DRU output decreased to -2.3Vdc (-110 rpm, the lower limit value), by a predetermined logic signal. Therefore, the target value of the governing system was reduced from 450rpm to 340rpm.

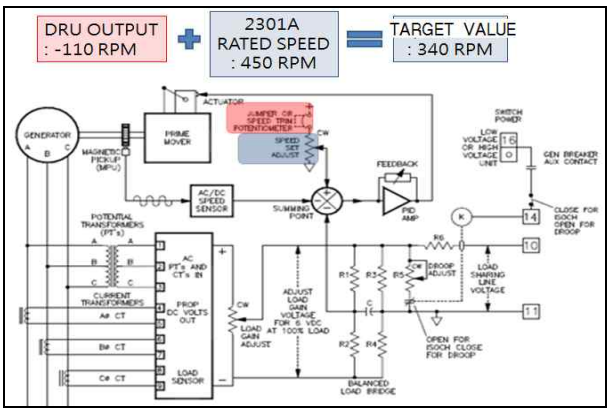



Fig. 5. Set. Value of governing system

In accordance with the result of the simulation presented in Fig. 6, it was confirmed that the rotational speed of the EDG is 450rpm with DRU output of 0Vdc and rotational speed of 340rpm with -2.3Vdc(lower limit value).

When an early stop signal is applied, the shutdown cylinder tries to reduce the rotational speed of the EDG. However, the final target value of the governing system is maintained at 450 rpm.

Thus, the governing system will attempt to correct the error between the reduced rotation speed of the EDG and the target value. At this time, the output signal of the governing system reduces the actuator output to the minimum (0Vdc) to increase the amount of fuel injection. Because the DRU output signal reduces to -2.3Vdc, the target value of the governing system is set to 340rpm. At this time the rotational speed was faster than 340 rpm. Thus, the output of the governing system increases in order to reduce the rotational speed.

After that, in the period when the rotational speed of the EDG falls below 340 rpm, the output of the governing system is the lowest (0Vdc) to generate a signal for increasing the amount of fuel injection. However, the fuel is not supplied to the EDG because the shutdown cylinder blocks the fuel.

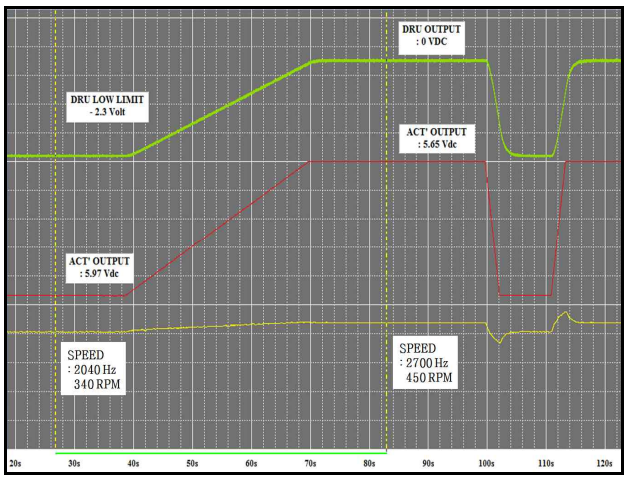



Fig. 6. Result of Simulation

*2.4 Control Signal from Outer Governing System*

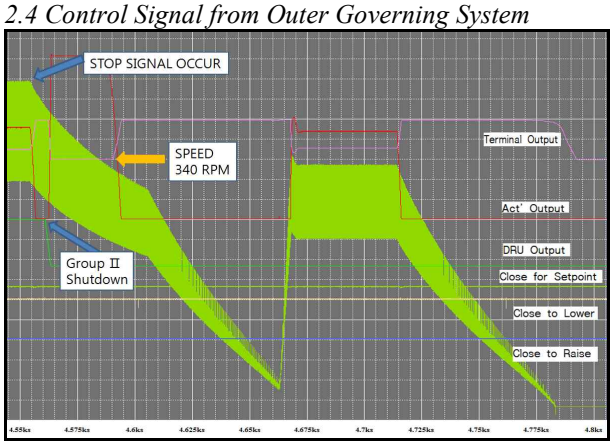



Fig. 7. Signals of Governing System

[1] The lower electric governor is the output signal level to Reverse Acting Type the fuel injection amount is increased.

Fig. 7 shows that there was no external control signal[2] in the period when the rotational speed of the EDG decreased and unintentionally restarted after the stop sign occurred.

*2.5 Mechanical Governor Output (Terminal Output)*

A rotary displacement sensor[3] was equipped with a mechanical governor output (terminal output) that records voltage changes according to the rotational angle to verify the operating status of the mechanical governor. Fig. 7 confirms that the rotation angle of the mechanical governor was opposed to the operation of the electric governor signal (actuator output). In other words, if the actuator output decreases, the terminal output signal increases to increase the amount of injected fuel. Conversely, if the actuator output increases, the terminal output signal decreases to decrease the amount of injected fuel.

*2.6 Fuel Rack Movement (Fuel Linkage, Fuel Injection Pump)*

The fuel racks, which adjust the amount of fuel to be injected into the individual cylinder, are connected to the fuel linkage through the spring shock absorber. The fuel linkage connects the mechanical governor and the fuel injection pumps. Therefore, even if the motionless fuel rack of a particular cylinder is stuck, it does not affect the movement of the mechanical governor, which is connected to the fuel linkage.

After a stop signal, it was found that the fuel rack of R7 cylinder was stuck by foreign material. Once the foreign material was removed, it was confirmed that the rotational speed of the EDG decreased sharply, as shown in Fig. 1. It was thereupon confirmed that the stopping time increased to 108sec because of sticking of the R7 cylinder fuel rack.

*2.7 Cause of Restarting*

In this case, the Minimum Starting Speed[4] of the EDG is 50 ~ 100 rpm[5].[2] Fig. 1 shows that the minimum rotational speed of the EDG is 55rpm and 123 rpm[6] for the mechanical governor (EGB 35P) before unintentional restart. At this time when rotational speed of the EDG was 55 rpm, the hydraulic pressure was formed by the oil pump inner EGB 35P and the mechanical governor got the power to move the fuel linkage and fuel rack[7]. Therefore, when the shutdown cylinder stopped blocking the fuel that was supplied into the combustion chamber, the EDG was still running at 55rpm (108 sec. after the stop signal) and at that time the fuel must be injected into the combustion chamber. So the EDG consequently started unintentionally because of its rotating speed and the injected fuel.

*2.8 Test Run*

To confirm the results of the root causal analysis, the stop process was demonstrated by a test run of the EDG. Before the test run, it was ensured that the fuel racks of all cylinders were free of movement. Variables other than fuel rack movement were the same as when unintentional restart occurred. Fig. 8 shows that it took 84 sec. to completely stop (0 rpm) and re-starting did not occur.

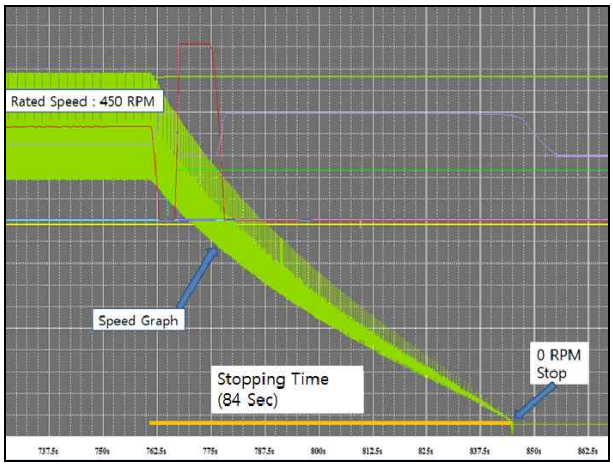


Fig. 8. Test Run

## 3. Conclusions

An analysis was conducted to confirm the cause of an EDG which was unintentionally restarting and running at 340rpm (rated speed is 450 rpm). Through a test run, it was confirmed that the results of the analysis are correct.

The cause of the EDG unintentionally restarting was that it still rotated at 55 rpm over the minimum starting speed at the moment when the shutdown cylinder stopped blocking the fuel, because of a stuck fuel rack at the R7 cylinder.

At the same time, the fuel that had been supplied into the cylinders (combustion chamber) by the governing system exploded and the EDG restarted unintentionally.[3]

The cause of the EDG running at 340 rpm after restarting was that the target value of the governing system had been changed to 340rpm by applying a logic signal after the stop signal occurred.

[2] Close for Setpoint, Close to Lower, Close to Raise
[3] RVDT: Rotary Variable Differential Transformer, rotational displacement sensors
[4] Minimum speed for the engine to be started.
[5] It is e the experimental value and there is a variation according to the ambient temperature.
[6] The gear ratio of the engine and mechanical governor is 1: 2.25.
[7] Experimental results of EGB 13P is formed in the oil pressure 90psi (6.2bar) at 123RPM

Through the analysis, it was found that only one stuck fuel rack can cause the EDG to fail to stop and unintentionally re-start.

If the capacity of the accumulator (Fig. 4. ⑥) is increased, the time during which the shutdown cylinder blocks the fuel can become longer. The rotating speed of the EDG consequently has the more time to decrease under the minimum starting speed (50 rpm). In other words, the EDG has a higher likelihood of stopping when one of the fuel racks of the EDG is stuck.

## REFERENCES

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[2] Jim Glasser, Air Start Capacity – Harris Plant, Enterprise Owners Group Information Bulletin, 2008.
[3] Klaus Mollenhauer, Helmut Tschoeke, Handbook of Diesel Engines, p. 88. 2009