THE DESIGN AND SIMULATION OF THE CONTROLLER PART OF AN ELECTROMECHANICAL CVT FOR CABURATOR GASOLINE ENGINES

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Abstract : *Constant Speed Drive (CSD) is a hydraulics transmission system which can produce a constant output rotational speed from a variable input rotational speed. In this research, the CSD principle will be used to produce the desired torque for a certain engine speed as an input. The use of the CSD principle will theoritically result in an unlimited gear ratio. This enables to produce a high torque from small engine power, which will prevent from engine stall during a heavy operation. Other objective of CVT designs is to obtain the best engine speed with respect to fuel consumption and air polution, for various power demands. Current research focuses on the design and simulation of the controller part of the CVT. It begins with the development of the modeling of the system, selection of hardware, microcontroller programming, and testing the system. The testing itself is a simulation of various operating conditions, i.e. engine speed and vehicle speed, then observe the gear ratio actual as compared to the ideal gear ratio. The results of the test indicate that the system being developed works properly with good accuracy. Further investigation for a better response is still required.*

Keywords : ***Electromechanical CVT, fuel efficiency, feedback control, engine speed, vehicle speed, planetary gears.***

1. Introduction

Constant Speed Drive (CSD) is a hydraulics transmission system which can produce a constant output rotational speed from a variable input rotational speed. In this research, the CSD principle will be used to produce the desired torque for a certain engine speed as an input. The use of the CSD principle will theoritically result in an unlimited gear ratio. This enables to produce a high torque from small engine power, with a consequence of small ouput speed. It is very important during uphill movement of a small engined vehicle with relatively high load. The system being developed will prevent from engine stall during this condition operation.

Operation of engines at improper speed also result in higher fuel consumptions and higher air polutions. Therefore, other objective of CVT designs is to obtain the best engine speed with respect to fuel consumption for various power demands. The best engine speed for a selected throtle position will be calculated by a mathematical model and will be used as a reference for determining the gear ratio of the transmission. Further development of the model can be on the least polution to the environment.

Figure 1 shows the differntial unit of a CSD. The engine will drive the carrier shaft. The load, in this

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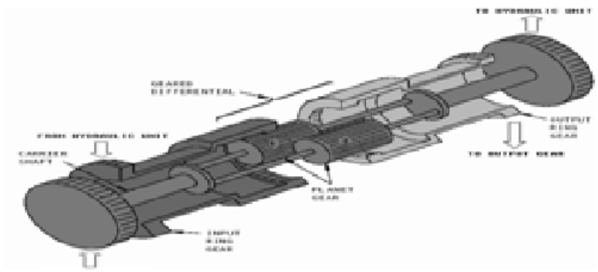

Fig. 1 The CSD differential unit [4]

research is the vehicle wheel, is connected with the output ring gear. If the input ring gear stands still from the carrier shaft, then the output ring gear speed is equal to the carrier shaft, and the gear ratio is one. If the input ring gear rotates in opposite direction from the carrier shaft, then the planet gear will rotate faster and this will add the output ring gear speed. Therefore the gear ratio will be less than one. If the input ring gear rotates in the same direction with the carrier shaft but faster, then the planet gear will rotate slower and this will subtract the output ring gear speed. Therefore the gear ratio will be greater than one. This mechanism explains the process of increasing or reducing the gear ratio by changing the speed and direction of the input ring gear rotation.

2. Methodology

This research covers the development of mathematical model for controlling the transmission, programming on microcontroller, testing of the model by observing the DC motor speed for varios vehicle operating conditions. The microcontroller will control a DC motor which will then control the gear ratio of the transmission. The gear set is designed for an 1000 CC four stroke gasoline engine. The test of the complete prototipe is beyond of the scope of the paper.

3. The Mathematical Modeling

Figure 2 illustrates the relationship between engines output torque, power, and engine speed [3]. Power equals to engine torque times engine speed.

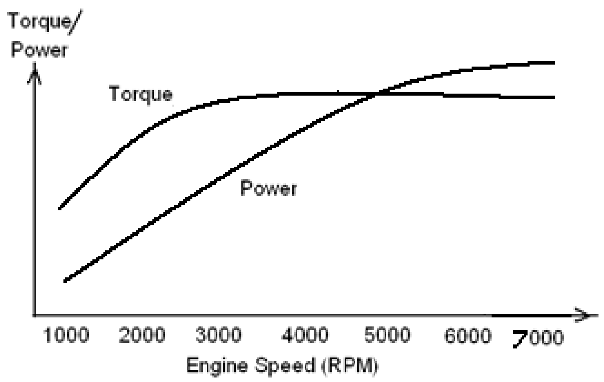

Fig. 2 Relationships of torque, power, and engine speed [3]

Figure 3 illustrates the curve of optimum efficiency trajectory of engine operation as described by Kazutaka Adachi, et al [1]. This figure indicates that the relation between engine speed and engine torque, and consequently the engine's power, at the optimum efficiency is unique up to the maximum engine output power. Operation beyond this point will increase fuel consumption without addition output power. Therefore, the discussion is limited to this point only.

The engine throttle position is actually indicating the demanded power by the vehicle's driver. With this throttle position, the engine can run in various speed, depends on the vehicle load, maneuver, and road condition. In other words, the engine may run at in-efficient operation. This is due to a fixed gear ratio transmission, both in a manual and an auto-shift manual transmission.

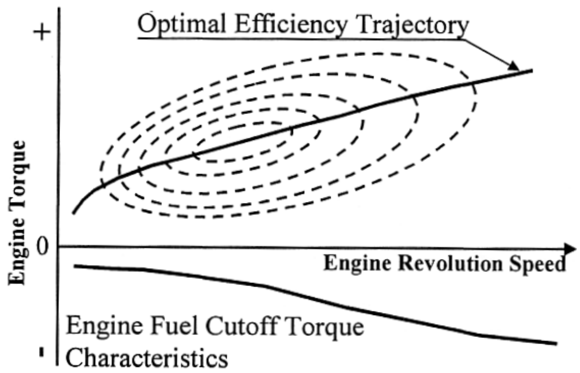

Fig. 3 The design engine operation curve [1, 2]

For a carburetor gasoline engine, the optimum efficiency speed has a unique relation with the throttle position, up to the maximum engine output power. This research uses throttle positions as the input of the transmission system, which indicates the demanded engine's power. Based on Fig. 3 a model is developed to represent the relationship between the throttle position and optimal efficient engine speed, as shown in Fig. 4. The linier model is a comparison for the developed model. The expression of the model is following.

$$RPM_{EFF} = 7000*(\theta_{THRO})^{1.5} + 800 \qquad (1)$$

where θ_{THRO} is the throttle position.

This model needs to be verified with engine test. However, this model is considered sufficient for the purpose of the initial transmission system design.

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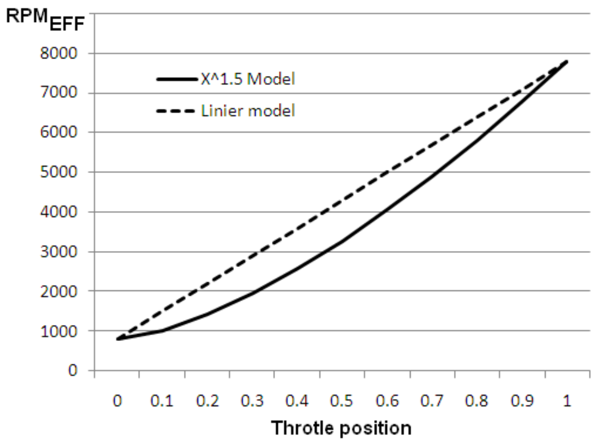

Fig. 4 Relationship of RPM with throttle position

In order to obtain the most efficient engine operation, the gear ratio, which is called gear ratio reference, can be calculated from the following equation.

$$GR_{REF} = \frac{RPM_{EFF}}{V_{VEH}} \quad (2)$$

where:

GR_{REF} = Gear Ratio Reference

V_{VEH} = Vehicle speed in rpm

RPM_{EFF} = the most efficient engine speed (in rpm) for the demanded power

The objective of the CVT transmission system is to shift the actual gear ratio to the gear ratio reference for the existing vehicle speed. The shifting is carried out by adjusting the electric motor speed which controls the gear ratio.

The actual gear ratio can be calculated as follows.

$$GR_{ACT} = \frac{RPM_{ACT}}{V_{VEH}} \quad (3)$$

where RPM_{ACT} is the actual engine RPM from the engine Tachometer.

From the descriptions above, the block diagram of the transmission system is developed and shown in Fig. 5.

The initial input of the system is the throttle position, which determines the value of the RPM_{EFF} by using Eq.(2). θ_{THRO} determines also the Actual engine RPM due to vehicle load, road condition and vehicle maneuver. At the current stage of the research the Actual RPM is calculated by the program in the microcontroller and it is assumed that Actual Engine Speed follows the most efficient engine speed curve, described earlier.

Figure 6 shows the design of the CSD based CVT where a microcontroller used to control a DC motor. The DC motor will control the gear ratio of the transmission. The system consists of a microcontroller ATmega 8535L with its minimum system, H-bridge as the driver of the DC motor, a DC motor, a speed encoder as speed censor of the motor, two potensiometers as throtlle position sensor and vehicle speed censor, and an LCD display for indicting the transmission variables.

4. The Software

The hardware of the system is designed to be self-suflcient in controlling the speed and the direction of the DC Motor. The heart of the system is the microcontroller. It is pre-programmed following a particular logic for the determined modes of operation. The program will collect data from the inputs, determine the control signal for the DC motor, and send this signal to the H-bridge. The program will also send signal to the display to show the value of the state variables, and also send signals to a PC for data recording and analysis. Figure 6 shows the flowchart of the program.

As shown in Fig. 7, there are three modes of operation namely the neutral, engine brake, and (normal) drive mode. The neutral mode is the result of switch selection or combination of throttle position in zero AND vehicle speed equal to zero. In this mode the DC motor speed is equal to the engine speed, but in opposite direction.

The drive mode occurs when the throttle position is not zero AND vehicle speed is in any value. This mode is applied when engine is driving the vehicle. At this mode the value of GRA will be adjusted to the GRR value so that the engine runs in the most efficient speed.

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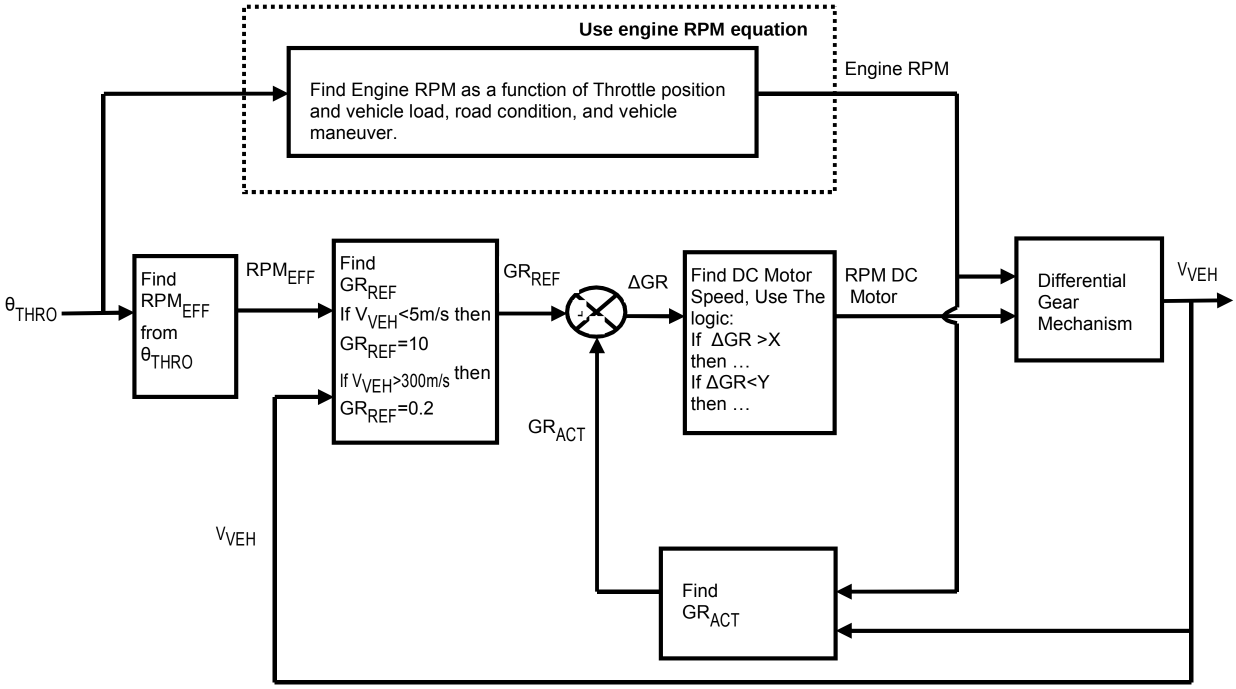

Fig. 5 The block diagram of the electromechanical CVT

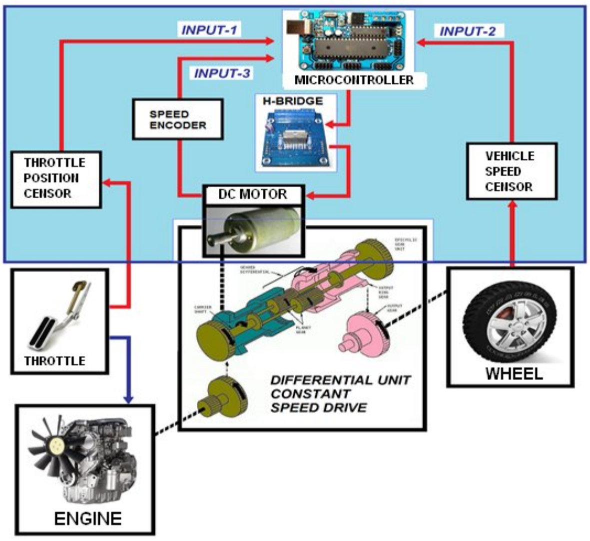

Figure 6 The design of the CSD based CVT

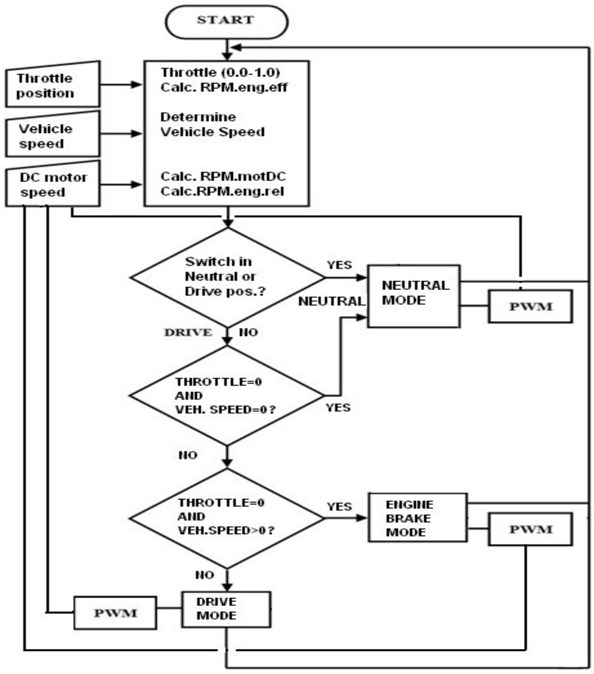

Fig. 7 The program's flowchart

The engine brake mode occurs when the throttle position is zero AND vehicle speed is not zero. At the beginning of this mode the value of GRA is used as the GRR, and therefore the engine is forced to runs at a certain speed and results in a braking effect. The program will maintain the engine speed to at least 2500 RPM by increasing the gear ratio if GRA results in less than 2500 RPM engine speed. This is to keep the braking effect and prevent engine stalls

.

5. Simulation

In this case simulation means testing the system by using inputs from potensiometer instead of directly from actual engine and vehicle speed, and throttle pedal. The controling of the throttle position and

vehicle speed in this simulation are carried out manually. The first simulation is for the nuetral mode.
For the neutral mode the simulation results shown Fig. 8 for idle engine speed and 20% throttle position, and Fig. 9 for 70% throttle position. For the idle engine speed the average error is 33 RPM or 0.4%, while for 20% throttle position the average error is 44 RPM or 0.6%. Error is the difference between the RPM.eng.eff and the DC motor speed. For 70% throttle position the average error is 62 RPM or 0.76%. A slight lagging of the DC motor speed can be seen in both of the figures. These lags result in maximum of 5.1% and 9.7% error for 20% and 70% throttle position, respectively.

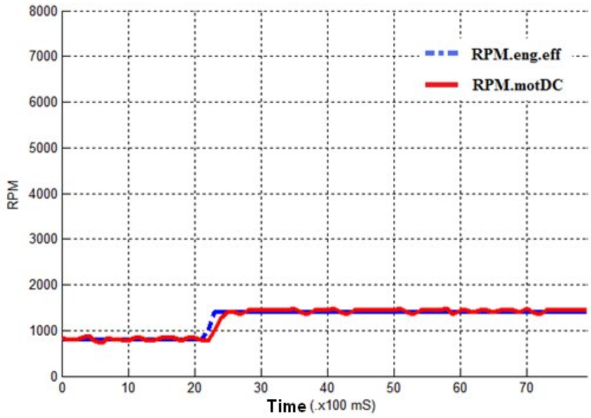

Fig. 8 Neutral mode with 0% and 20% throttle position

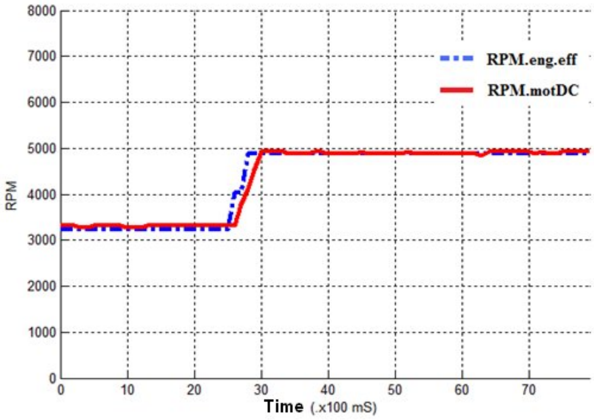

Fig. 9 Neutral mode with 70% throttle position

The next simulation is the drive mode which follows an operating scenario depicted in Figure 10, which is divided into 7 steps. As shown in Fig. 10 the throttle position varies from 0% to 50% for the simulated schedule time. The vehicle speed varies also with the time.

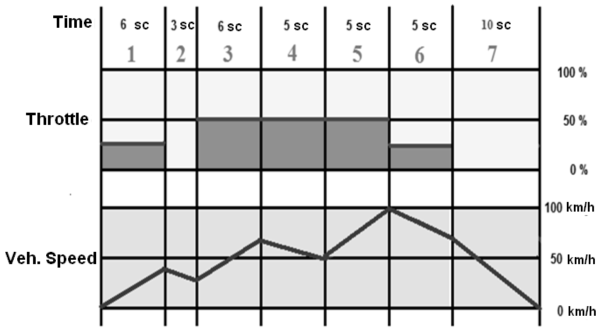

Fig. 10 The scenario of simulation

For the drive mode scenario above, the results of simulation are shown in Figures 11 until 15. Figure 15 shows the history of the GRR and GRA along the scenario of the simulation. The error is defined as the difference between GRR and GRA. As shown in Fig. 1, the step 1: start moving, the gear ratio reduces rapidly as the vehicle speed increasing. The error at this step the average and maximum error are 0.9% and 5.6%, respectively.

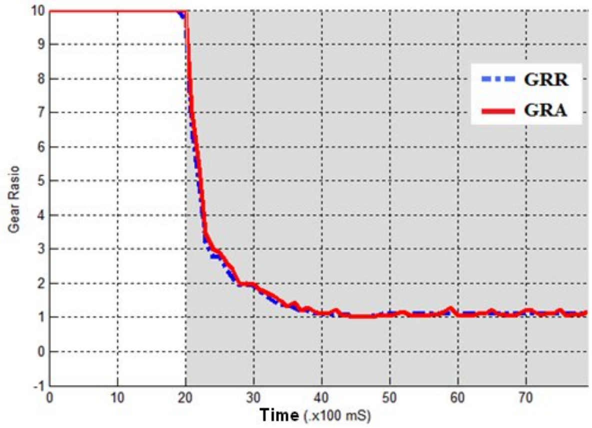

Fig. 11 Drive mode step 1: start moving

For step 2: throttle released, shown in Fig. 12, , the average error is 1.7% and the maximum error is 5.66%. The average error is relatively large due the speed of the DC motor is very low and probably change in direction. At this situation, the value of PWM is low and makes the response of the DC motor is inaccurate.

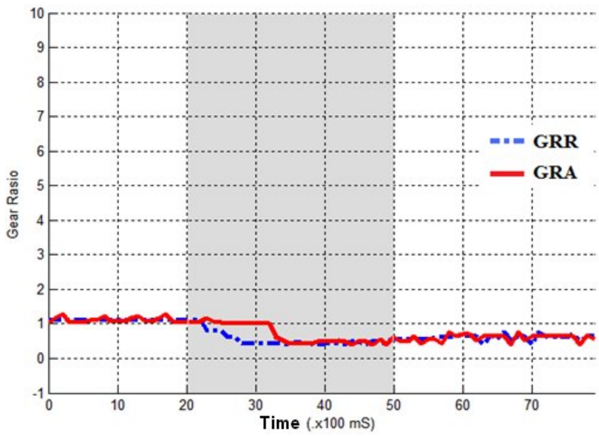

Fig. 12 Drive mode step 2: throttle released

For step 3: accelerate, shown in Fig. 13, the average error is 1.33% and the maximum error is 6.06%. The average error is slighly better. This is because the speed of the DC motor is still low but already leaving the changing direction zone.

For step 7: braking and stop, shown in Fig. 14, the average error is 1.55% and the maximum error is 7.27%. The average error and the maximum error is realtively large. Further investigation needs to be carried out whether these are resulted by engine brake action forced by the system. A record on the engine RPM will be required, but up to this stage the engine RPM is not recorded in the computer.

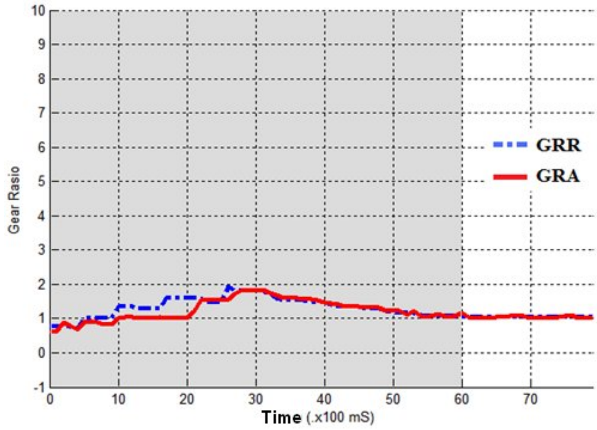

Fig. 13 Drive mode step 3: accelerate

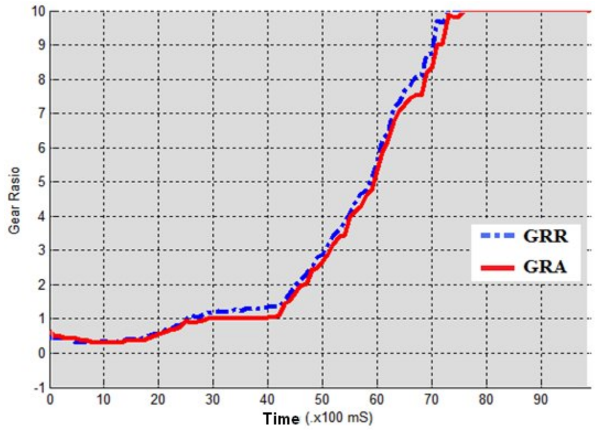

Fig. 14 Drive mode step 7: braking and stop

6. Conclusions

Based on the result of the design and simulation above, it can be concluded that the system works properly with relatively good accuracy. For the neutral mode, the average error is low but the maximum error is still high. For the drive mode, in certain band of speed the response of the system still need to be improved, especially when the DC motor speed is very low.

7. Acknowledgement

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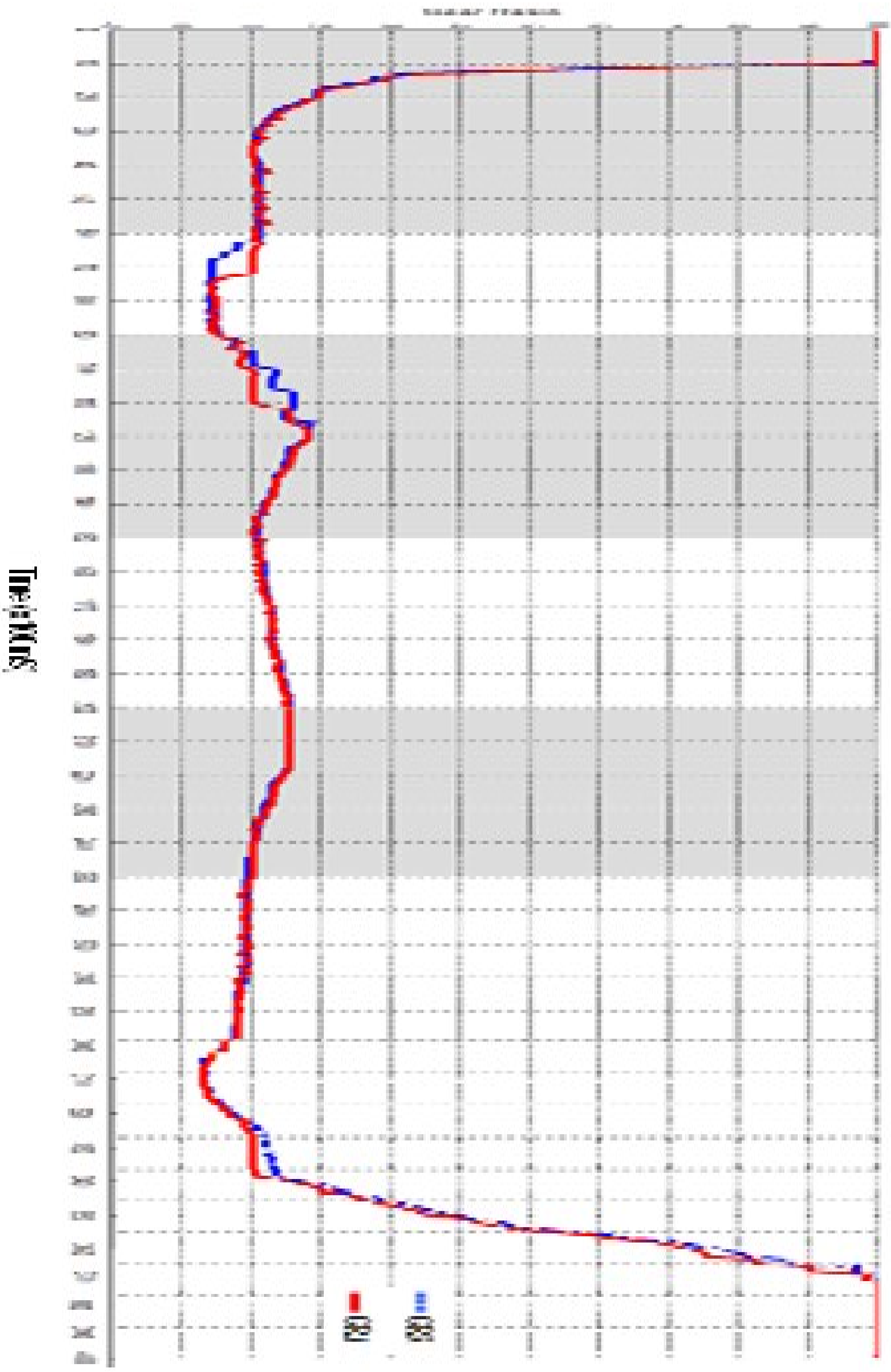

Fig. 15 The history of the GRR and GRA along the simulation scenario

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