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Study of The Inhomogeneity Between Work Cycles in An Internal Combustion Engine

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Abstract

Analysis of the main factors causing instability in an internal combustion engine is a fundamental problem in operation research and engine design. The inhomogeneity between work cycles is the cause of the fluctuated power as well as other working parameters of the engine. It is expressed through the amount of fuel supplied to the cycle and the quality of the combustion process. The problem is to find a way to reduce the instability. The creation of devices for instability control based on nonlinear dynamic method is a new direction in studying the essence of inhomogeneity between work cycles. This paper presents experimental results on the instability of the combustion process in an internal combustion engine through the control method of fuel supply time. Studying the orderly structure of the resulting time-series pressure graph will further explain the essence of the inhomogeneity. Based on the results of the investigation of the pressure turbulence in the engine cylinders as well as the inhomogeneity between work cycles determined entirely by random processes, it will be possible to generate a different form of pressure graph using a suitable fuel injection timing device. The selection of signal interval control for injectors is studied and presented in this paper that is the basis for further studies to improve the efficiency of internal combustion engine in each operation mode.

Keywords: Inhomogeneity, work cycle, turbulent pressure, combustion process, internal combustion engine.

1 Introduction

The instability of combustion process (inhomogeneity between work cycles) has been a concern since the beginning of the design development for the internal combustion engine. This inhomogeneity can cause fluctuations for the engine performance, as well as the amount of fuel burned and other parameters of the working process. According to the analyzed results that is an inhomogeneity between work cycles will reduce the value of the average efficient moment up to 18-20%. Therefore, the combustion instability has been identified as a basic problem in an internal combustion engine. A difficult issue of inhomogeneity between work cycles is that it is unpredictable, which causes the complicates in controlling the engine. Identifying and eliminating sources of instability has been one of the main issues in the development and improvement of internal combustion engine over the years [3,4]. Despite the considerable efforts have been made to identify various destabilizing factors recently, the problem of controlling stable combustion has not unsolved in an internal combustion engine yet.

According to Analyst J. Heywood [1], the main factors make instability of combustion process including:

- Aerodynamics of the flow in the engine cylinder during combustion process;
- Amount of fuel, air and residual gas supplied to the cylinders;
- Local composition of the gas mixture near injectors, spark plugs.

It is possible that many different turbulences affect the working process in an internal combustion engine causing it to occur randomly. In the case of an internal combustion engine that is highly sensitive to operating conditions, the possibility of turbulence (the defining sign of turbulence) should be considered. Pressure variations in the engine cylinders can arise from complex dynamics which lead to noncircular conditions with random components. Thus, the main problem is to understand the nonlinear kinematics through the analysis of pressure changes in engine cylinders [1]. To achieve this goal, it is necessary to focus first on empirical research on the inhomogeneity between work cycles of in an internal combustion engine, including the study of the effect of forced action on the its working process by controlling the amount of fuel supplied to the cycle.

2 Fundamental Method in Controlling Turbulent Condition

2.1. The fundament in building the problem of turbulent conditional control in the discrete and continuous dynamic systems

The main idea of the experimental study is considered in this paper that based on the application of one of the specific methods to control turbulence. For the experimental system, it is observed the rule of pressure turbulence in the cylinder, using some method to control this turbulence requires the adjustment of the time series taken by the system and gives a stable limit period.

The most common method of controlling the turbulent condition has been the Ott-Grebogi-Yorke and Piragas methods [4]. This was one of the first methods that opened the solution to stabilizing the imbalance of turbulent condition. This method solved the system of ordinary differential equations with signal effects of the discrete control at several points in the vicinity of a fixed point corresponding to the expected period. This method has used delayed feedback and the delay time is chosen closed to the period of the unstable periodic root.

The essence of the method of controlling the turbulence in the dynamic system is as follows. Assuming that in the dynamic system, selecting the parameters observed a turbulent condition, it is reflected the presence of a set of unstable periodical orbits. In this case, the problem is to stabilize one of those turbulence orbits and return to a periodical stabilization process. According to C.L Magnit [4], this solution can be combined to create an extended (additional) dynamic system of higher phase-space dimensions, making sure that the unstable orbit of the original system is a projection of stable periodical orbit of the extended system.

Therefore, it is possible to build a problem and find a practical solution to control turbulence in an internal combustion engine, including building an auxiliary system that works in the simple case in accordance with the discrete rule (discrete limit cycle). The phase coordinates of the auxiliary system can have many parameters, or can be controlled during the operation in an internal combustion engine (ignition time, fuel supply time, voltage at the electrodes of spark plugs, etc.).

2.2. Approach method to prevent instability between work cycles in an internal combustion engine

The idea of using the above turbulent control methods to suppress instability between work cycles of combustion process in an internal combustion engine can be expressed as follows. An auxiliary dynamic system is created, where the role of a new variant is represented by an independent parameter that adjusts the fuel supply interval. In this case, the simplest property of such a variant may be a sequential adjustment of the fuel supply, ensuring a corresponding addition or reduction of the basic fuel over each cycle, which is determined by the injection interval. In this event, it is assumed that there is a stable limit cycle in an auxiliary system, and the engine operation in which takes place under the condition of suppressed turbulence. Obviously, the stable limit cycle is a double cycle (i.e., for a four-stroke internal combustion engine would be 8π). Besides, taking into the occurrence of random turbulence when controlling instability of combustion process between work cycles, the suppression of turbulence will not be absolute.

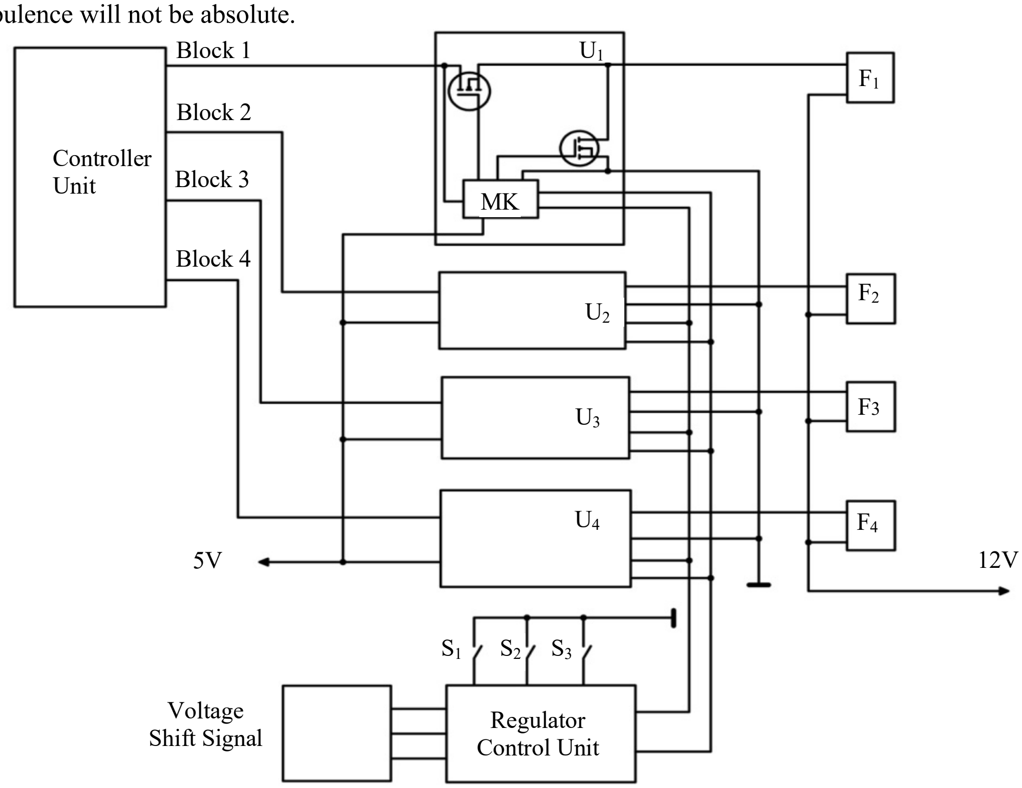


Figure 1. Block diagram of the device for adjusting the amount of fuel supply

To test the constructed assumption, a special device has been developed and manufactured (control device for injection timing). Fig.1 depicts a block diagram of a device as part of an engine control system, where: U1 - U4 is a time shift calibrator supplying voltage to the engine injectors; F1 - F4 are engine injectors; S1 - S3 are the buttons of the regulator control unit; MK- Microcontroller.

The device works as follows. Initially the device is turned on, the calibrators (U1 - U4) do not make any changes to the engine operation.

When power is applied to the device (5V), a pulse signal begins to be generated (from 1 to 10), corresponding to the setting deviation of the voltage supply time to the engine injectors (from 0.01 to 0 ,1 with a resolution 0.01). Buttons S1, S2 set the deviation of the voltage supply time to the injectors (S1 – up, S2 - down).

When the button S3 is turned on, the pulse signal stops generating and the microcontroller of the regulator writes the set value of the time of applying voltage to the engine injectors (F1 - F4). Then, each regulator measures the time of applying voltage from the engine control block to the injectors, dividing this value by 100, multiplied by the set correction value. The obtained value is the shift of the timing of applying voltage to the engine injectors.

When the device is turned off, the signal from the engine control unit to the engine injectors does not change.

3 Results Of Experimental Research

The experiment is intended to record the pressure values in one of the engine cylinders at the selected idling speed for a certain period of timing, about 100 work cycles, as well as other measurement parameters. An experiment is carried out with two working options of the fuel supply system:

Option 1: Performing under control of the standard system (ECU);

Option 2: Performing under the control of the control device for the injection timing.

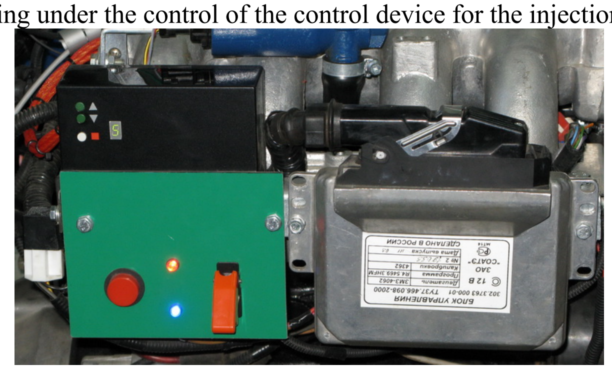


Figure 2. Control device of the injection time

As presented above, the operation of control device for the injection timing (Fig. 2) is as follows: ensuring the effect of regulating the interval of the fuel injection pulses and the generated output signals are alternating pulses with difference from original pulses such as the first signal increases $\Delta\tau$, the second signal decreases by $\Delta\tau$ (Fig.3). The signal correction level is set as a percentage and can vary from 0 to 10%.

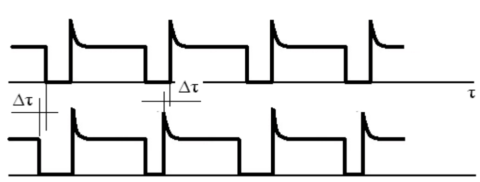


Figure 3. Controlling the oscillated signal

When the engine is running at stable condition, the shape and interval of the fuel injection pulses are recorded.

Before starting the experiments, the engine was started and heated to operating temperature at idling speed. Fixing at each rotational speed at which the experiment will be performed. When the computational load is reached, data acquisition begins: the amplifier is turned on, the USB oscilloscope is started as a recorder. At the rotational speed in stable condition, the required number of time series is recorded and saved with a serial number, entered in the test report. Simultaneously, the recording process is performed and the current working parameters are saved. At the end of recording in the stable condition, a test is performed using the control device for the injection timing. To do this, using the buttons located on the front panel of the unit, the offset value Δτ (in %) of the fuel injection duration is set. The time series of the pressure in the cylinder are studied by using a control device of the injection timing and without it are shown in Fig. 4 and 5.

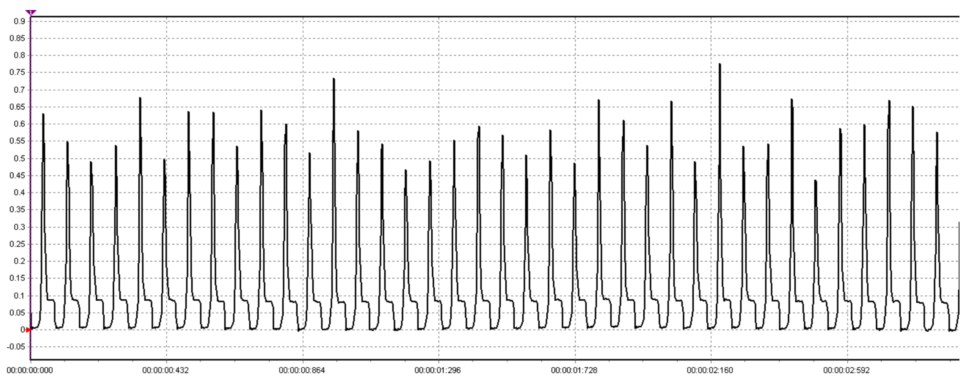


Figure 4. The pressure in the cylinder of the ISUZU 4JJ1B engine at idling mode n=1600 rpm when the control device of injection timing is not used.

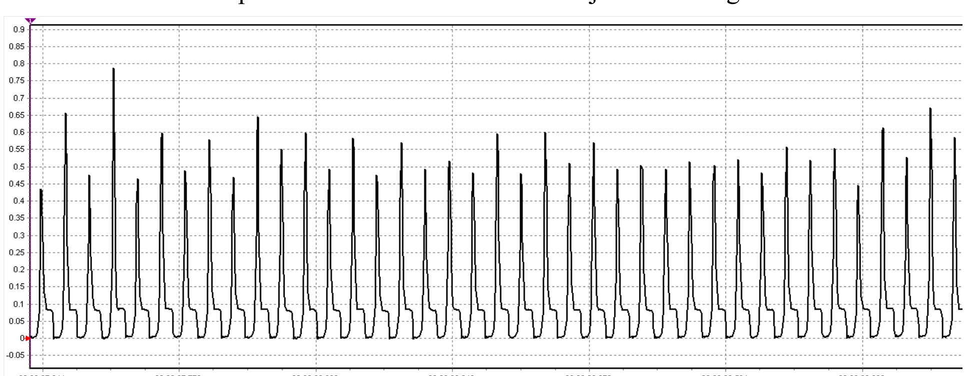
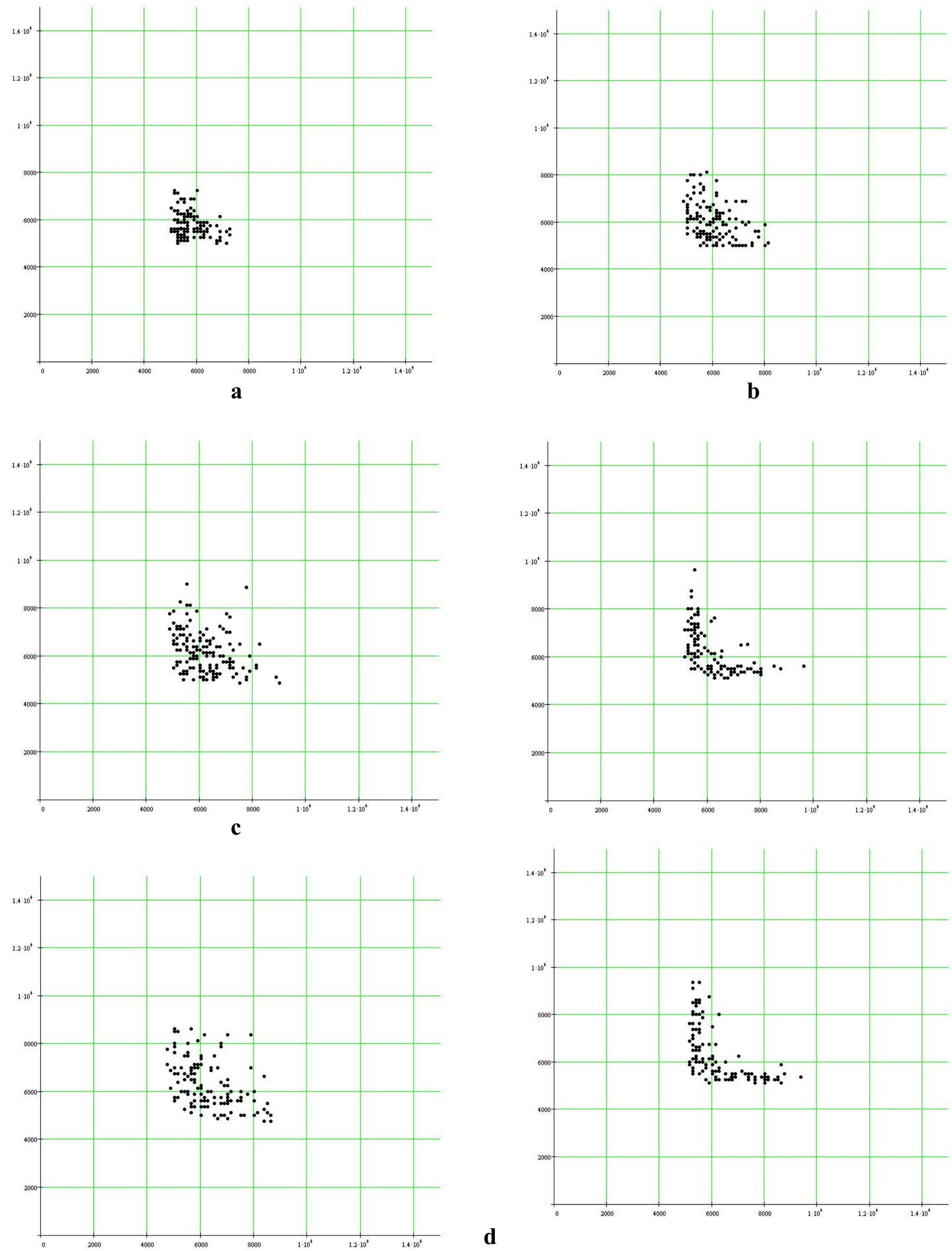


Figure 5. The pressure in the cylinder of ISUZU 4JJ1B engine at idling mode n=1600 rpm when using the control device of injection timing (6% correction)

The USB oscilloscope is used as a spectrophotometer to indicate the frequency component of the pressure signal in the cylinder.

After testing, the obtained data will be processed and analyzed. The analysis includes to plot the dependence of the maximum pressure of the next work cycle on the maximum pressure of the previous work cycle.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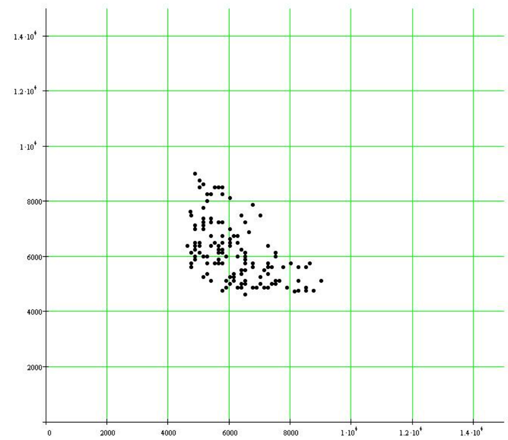

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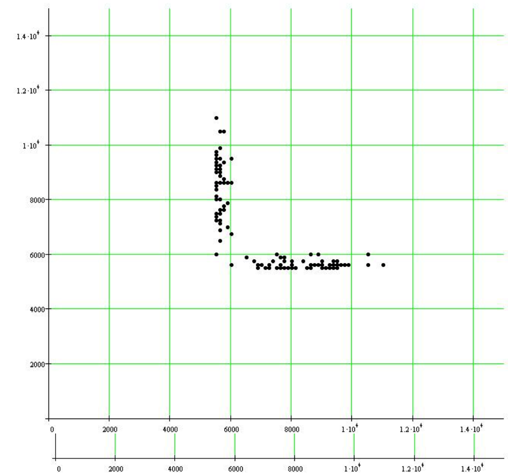

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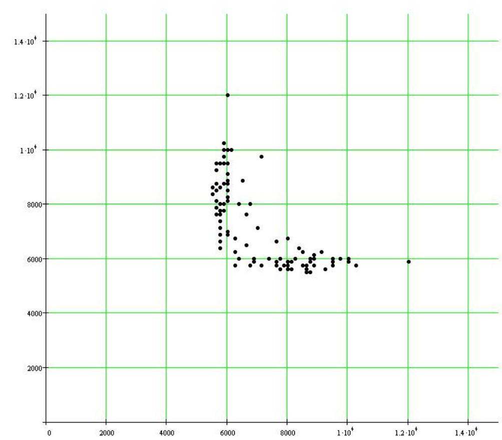

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k

Figure 6 (a-k). Characteristics of the effect of control device for the injection timing to inhomogeneity between work cycles

The dependency analysis in Fig. 6 (a-k) shows at large deviations from the standard injection interval that the characteristics of the significant inhomogeneity change, the structure of wedge shape is appeared clearly at the position of pressure peaks. For example, in the graph of Fig.6i corresponding to the 8% correction value is shown that the minimum value of the corresponding peaks about 0.55 MPa. In this case, the maximum peak pressure is between 0.6 MPa and 1.0 MPa. Thus, the initial turbulent picture of dependency in Figure 6a is built into a more ordered structure. This demonstrates the effect of the control device for injection timing on the inhomogeneity between work cycles in the engine.

The analysis also shows that at low revolution per minute, a decrease in non-uniformity is observed (area of distribution of maximum pressure values between work cycles decreases) when the deviation of the control device for injection timing is small (1 and 2%).

4 Discussion And Conclusion

The results of experimental studies presented in this paper show that the building of turbulent control systems is based on the methods of the nonlinear dynamic, especially the C.L. Magnit, this may be a promising orientation in studying the essence of inhomogeneity between work cycles in an internal combustion engine. It was found that the character of inhomogeneity between work cycles changed significantly when the fuel supply interval was corrected to a value of $\pm \Delta\tau$ (from 0 to 10% of the basic injection interval). For each rotational speed of crankshaft, the distribution pattern of the ordered the highest pressure value is observed at different values of $\Delta\tau$.

The appearance of an ordered structure of the resulting time series graph requires further analysis and interpretation. On the other hand, the turbulent development of inhomogeneity between work cycles were determined totally in random processes, it would be expected that a different form of graph in using a control device for fuel injection timing at $\Delta\tau$ is relatively large. It is possible that in this case the original distribution of the points should gradually be divided into two parts. However, this is not observed, and the minimum values of the pressure peaks in the half-cycle have a much smaller scattering than the maximum values. This characteristic requires a number of assumptions to be made and resolved.

The selection in controlling of signal interval for engine injector is studied and published in this paper that can use for further studies to improve the efficiency of internal combustion engine in each mode. In effect, the reduction in fuel supply time during the cycle is essentially a variant of "partial" cut - off in the cylinder.

5 List Of Acronyms

ECU: Engine Control Unit
USB: Universal Serial Bus

6 Conflicts of Interest

The authors declare no conflicts of interest.

7 Acknowledgment

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8 Author's Contribution

Quoc Toan Tran participate in the creation of article writing ideas, responsible for reporting results, check and complete the paper.

Ngoc Thanh Huynh perform the calculation process, write the article.

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