

# GLOBAL JOURNAL

OF RESEARCHES IN ENGINEERING: B

## Automotive Engineering

Study on Simulation

Isolated Traffic Signal Control

Highlights

Evaluation the Dissipated

Investigations on the Potential

Discovering Thoughts, Inventing Future

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AUTOMOTIVE ENGINEERING

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## MAGLEV TRAINS: Trains that Fly

By Abhinav Chugh, Aditya Gupta & Ishita Bhargava

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**Abstract-** Magnetic Levitation is a technology that has been experimented with intensely over the past couple decades. It wasn't until the last ten years when scientists began to develop systems that would use magnetic levitation as a means of transport. This paper outlines the methods behind magnetic levitation, as well as the technologies implemented using the levitation. The implementation of a large-scale transportation system using magnetic levitation has huge social as well as economical effects. These aspects are looked at in a number of situations to see if the effort in producing a system using magnets is worth the time and eff.

The MAGLEV TRAINS have a countless number of advantages which are making us to think more towards the MAGLEV TRAINS than the conventional trains.

High speed trains like MAGLEV TRAINS moves very smoothly as compared to the other conventional trains due to absence of wheels in it.

**Keywords:** *magnetic levitation, train, propels, thrust, and wheels.*

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# MAGLEV TRAINS: Trains that Fly

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**Abstract-** Magnetic Levitation is a technology that has been experimented with intensely over the past couple decades. It wasn't until the last ten years when scientists began to develop systems that would use magnetic levitation as a means of transport. This paper outlines the methods behind magnetic levitation, as well as the technologies implemented using the levitation. The implementation of a large-scale transportation system using magnetic levitation has huge social as well as economical effects. These aspects are looked at in a number of situations to see if the effort in producing a system using magnets is worth the time and eff.

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## I. INTRODUCTION

Some forces in this world are almost invisible to the naked eye and most people throughout the world do not even know they exist. Magnetic field is one of the invisible forces present in this world which have a tremendous power hidden in it which can only one can feel. It is due to the power of the magnetism of the earth that the world spins and thus creates things like gravity.

The word MAGLEV which is derived from magnet & levitation uses magnetic force to levitate the trains and propel the train with the help of it. In it the train coaches are levitated (to hold aloft) from the tracks or guide ways using the magnetic force generated which creates a thrust and lift.

MAGLEV TRAIN uses this powerful magnetic field power to propel the vehicle in a more powerful and uses energy in a proper way. The vehicle propelled using magnetic levitation technology moves more smoothly than the wheeled conventional means of transportation. Due to the absence of the wheels there is a no problem of friction that we see in a conventional wheeled train. It even does not use much of energy as most of the energy which is required is used to overcome the air drag or we can say resistance which is caused due to the air. The conventional trains are faster but maglev trains are much faster than conventional train, due to this speed maglev trains hold a speed record for any type of rail transportation. There are many advantages of MAGLEV TRAINS over conventional trains which are as follows:

- Since train is lifted above the tracks so there is no friction so these trains easily move at a higher speed.
- The system is very safe and eco friendly.
- No risk of fire as there is any fuel required in it.
- The train speed is much higher than the normal conventional trains.
- A very little amount of electricity is required in it only to portion of the track which is to be used.

## II. WORKING PRINCIPLE

MAGLEV TRAIN uses the electromagnetic force which is generally created between the magnets mounted on the bottom of the vehicle and the coils which are attached to the ground or guide way over which the trains move. The following will explain the basic working principle over which these trains work:

### a) Levitation

Support electromagnets built into the chassis and pull along the entire length of the train to the guide way solenoid, which is called the ferromagnetic reaction rails. Placed on each side of the guidance magnet train along the track center and to keep it guided along the train. All the electromagnet electronic control in a precise manner. It ensures that the train is always from even when it is not moving guide way distance of 8-10 mm suspension. This suspension system is a vehicle-mounted battery, they consist of linear generator, when a train traveling charging power supply. The generator is integrated in the suspension by the electromagnet coil extra cable. Inductive current generator driven during use of the propulsion magnetic field harmonic, which is due to the long-term side effects such charging process of the stator groove, is not useful to promote consumption of the magnetic field. The train can rely on this battery power for up to one hour without the need for an external power supply. Suspension system is independent of the propulsion system.

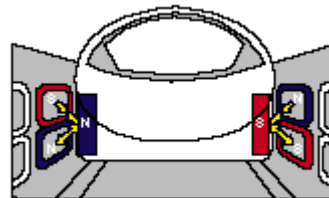


Figure 1: Levitation

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### b) Propulsion

Maglev System synchronous long stator linear motor propulsion and brake simultaneously. It operates as a normal rotation of the motor, the stator is cut and stretched along the lower guide way. Internal motor winding, alternating current generation without contacting the traveling magnetic field on a moving vehicle. In the vehicle function as an incentive portion (rotor) of the support.

In boot mode propulsion system is activated only in the actual operation of some of the vehicles. The speed can be continuously adjusted by varying the frequency of the alternating current. If the line of approach direction is reversed, the electric motor becomes a generator; it destroyed the vehicle without any contact. Braking energy can be re-used, and fed back into the grid. Three-phase stator winding generating an electromagnetic traveling field and exchange it with a moving train when the current supply. Support from the electromagnet electromagnetic field (rotor) to pull it together. Direction and speed of the magnetic field of the stator and rotor are synchronized. Maglev rotational speed from standstill to full speed by simply adjusting the frequency of the alternating current variation. In order to completely stop the train, traveling direction of the magnetic field is reversed. Even during braking, without any mechanical contact between the stator and rotor. Instead of energy, the magnetic levitation system as a generator, fracture energy is converted into electricity, which can be used elsewhere.

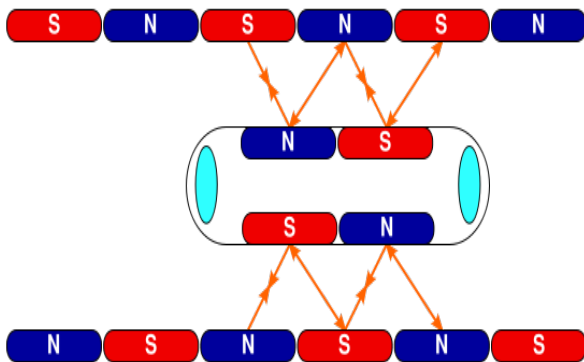


Figure 2: Propulsion

### c) Stability

For all the success of the suspension and controls 6 axes (degrees of freedom; three translational and three rotational) permanent magnets and electromagnets or diamagnets superconductor or a combination of attraction and repulsion, and fields can be used. From Theorem Hawthorn won at least one stable axis must be present for the system to successfully float, but you can use other ferromagnetic stable axis. Static stability means that any small displacement from a stable equilibrium departure results in a net force pushing it back into balance. Hawthorn won Theorem confirmed, it is not possible to use stable

suspension only static, macroscopic, along fields. Force on any combination of gravity, electrostatic and magnetic static fields acting on the paramagnetic object will make the position of the object, at best, erratic along at least one axis, and it may be unstable along all axes balance. However, several possibilities exist, and the suspension possible, for example, using an electronic stability or diamagnetic material (as a relative magnetic permeability less than one); it can be shown that the diamagnetic material is stable along at least one axis, and along All axis stabilization. Conductor may have a relative permeability of alternating magnetic field below, so some configurations using a simple AC driven electromagnet is self-stabilizing. Suspension system to damp any vibration-like motion that may occur dynamic stability.

Magnetic field is a conservative force, and therefore there is no built-in damping in principle and in practice many of the suspended program is under damped, in some cases, negative damping. This may allow for the presence of vibration modes may cause the program to leave the stable region.



Figure 3: Stability

### d) Guidance

The electronic control located on both sides along the entire length of the vehicle pull the vehicle side of the stator ferromagnetic installation guide way package supports magnet. Located in the guidance magnet holding the transverse rail vehicles along the entire length of the sides of the vehicle. Electronic systems ensure the gap remains constant (nominally 10 mm). Hover, maglev requires less power than air-conditioning equipment. Suspension system from the car batteries, so they are independent of the propulsion system. The vehicle can hover up to an hour without external energy. On the road, the car battery is integrated into the support by the magnet linear generator charging.

Maglev hover track rail. It can be installed at grade or elevated slender columns up to 62 meters in length by the individual steel or concrete beams. Guiding or steering refers to the need to follow the vehicle lateral force rails. The force necessary to

complete a similar manner to the suspension force, whether attractive or rejection. The same vehicle magnet board, which provides lift, can guide or a separate guidance magnet can be used simultaneously. They use Null Flux systems, also known as zero-current system, wound so used, so that it enters two opposing, AC coil Variant Field. When the vehicle is straight field position, no current flows, but if it moves offline this creates a change in magnetic flux, which generates push it back into line.

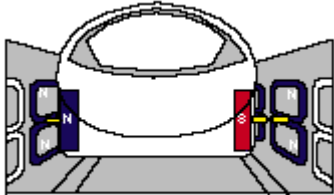


Figure 4: Guidance

### III. MERITS

Foremost advantage of maglev train is that it has no moving parts such as conventional trains do so, wear parts is minimal, and reduces a significant degree by the maintenance costs. More importantly, between the train and the track without physical contact, so there is no rolling resistance. Although the electromagnetic air resistance and friction do exist, but that does not hinder their ability to clock speeds of over 200 mph. Absence wheel also comes as a blessing, because you do not have to deal with a deafening noise is likely to be environmentally friendly Maglev's also have with them, because they do not resort to the internal combustion engine. These trains weathering resistance, which means rain, snow, or cold, do not really interfere with their performance. Experts believe that these trains a lot safer than their conventional, because they are equipped with advanced equipment, the most advanced security system that can keep control of things, even if the train speed cruising.

### IV. DEMERITS

The advantages of maglev system on their own seem promising, but not enough to cover the maglev biggest problem: the high cost of the initial installation generated. Although the introduction of a late fast conventional trains, which run on a slow train tracks mean fine, magnetic levitation trains need a new set right from scratch. The present rail infrastructure is of no use maglev's, which must either going to have to create a magnetic levitation system or a new set of replacement, both of which will cost a decent initial investment amount. Even cheap compared to EDS, it is still expensive compared to other models. If these trains are advantages and disadvantages to contend with each other, it can be a bit difficult to come to a specific conclusion. Although the initial cost of

setting something higher, a developed country like the United States will not have to worry about the entire infrastructure must be replaced with a new one will be something that will have to catch up with the fact that an expert-22 situation. But obviously, we would have to abolish their disadvantages, if we invest in maglev trains. If successful Shanghai maglev train commercial is to be considered, these trains can be reliably considered future traffic system.

## V. CONCLUSION

Maglev trains will soon be the new way of transport. Several obstacles in the way, but there are also some more improvisation that nothing is impossible. Since there is no engine, no wheels, no pollution, new energy sources, floating in the air, this concept has taken decades to develop and recently its true function have now been achieved. To compete with the high-speed aircraft, ships and effectiveness, security and conventional trains, cars with comfort, this seems to be a promising means of transport. Maglev trains are environmentally friendly, noise pollution is minimized because there is no wheel-rail contact (friction). Maglev trains 150 mph standing work cannot be heard 25 miles away people. The system encourages the conservation of land, where land is expensive or unavailable which is very useful. For the train tracks are easily built on an elevated platform; it is under construction and development opportunities, prevent land anatomy, but also reduce the conflict of animals. This statement can be proved in the construction of the rail throughout the residential areas, schools, places of worship, tourist attractions, practical magnetic levitation train, however, the cost of building these trains run to billions of dollars. The high cost of these trains is the only deterrent to prevent the train being performed everywhere. In this area with an active interest in governments around the world continue to study can be reduced along with the cheaper options without sacrificing security costs greatly.

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## Evaluation the Dissipated Energy by the Automobile Dampers

By Veronel-George Jacota

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**Abstract-** Simulation of suspension system and evaluation of dissipated energy by the system highlights the potential of the car operation mode, where the suspension can provide a significant amount of power. A roughness road profile and a car with elastic suspension springs and stiff dampers can provide significant energy. This energy varies between 4% and 8% of the energy consumed by the engine vehicle, considering the road speed profiles below 60 km/h and a vehicle with reduced rolling resistance and drag coefficient.

**Keywords:** *simulation, suspension, stiffness, damping, road profiles, dissipated energy.*

**GJRE-B Classification:** FOR Code: 090299



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# Evaluation the Dissipated Energy by the Automobile Dampers

Veronel-George Jacota

**Abstract-** Simulation of suspension system and evaluation of dissipated energy by the system highlights the potential of the car operation mode, where the suspension can provide a significant amount of power. A roughness road profile and a car with elastic suspension springs and stiff dampers can provide significant energy. This energy varies between 4% and 8% of the energy consumed by the engine vehicle, considering the road speed profiles below 60 km/h and a vehicle with reduced rolling resistance and drag coefficient.

**Keywords:** simulation, suspension, stiffness, damping, road profiles, dissipated energy.

## I. INTRODUCTION

Characterization of automotive suspensions, in terms of energy dissipated by the suspension dampers while running, is a complex process that takes into account a number of factors, such as road profile, vehicle characteristics, running speed. All these factors contribute to determining the conditions under which the dampers dissipate a large amount of possible energy. In order to simulate the systems suspension operation and to evaluate the dissipated energy by the system, there were considered the following parameters:

- road profile;
- mass parameters and general organization of the car;
- operating parameters of the suspension;
- simulation conditions.

## II. ROAD PROFILE

The road profile is comprised of two components:

- the road microstructure;
- the road macrostructure.

The road microstructure road represents the uneven humps of tread, felt by the vehicle driver as vibrations or small oscillations. This is divided into four classes, depending on the variation of high road irregularities ( $\Delta h$ ) in relation with theoretical nominal profile, measured in mm, [1]:

- ISO A-B,  $\Delta h = \pm 15$  mm;
- ISO B-C,  $\Delta h = \pm 25$  mm;
- ISO C-D,  $\Delta h = \pm 50$  mm;
- ISO D-E,  $\Delta h = \pm 100$  mm;

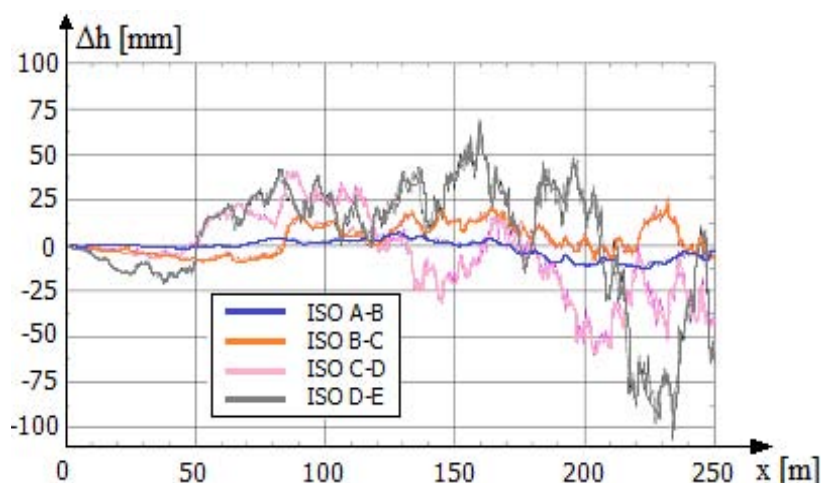


Figure 1: Microstructure of road profile

The road macrostructure is the longitudinal profile of the road, being characterized by the following parameters, [2]:

- the maximum longitudinal gradients,  $\alpha$ ;

- the minimum radius of the convex road connection,  $R_{convex}$ ;
- the minimum radius of the concave road connection,  $R_{concav}$ .

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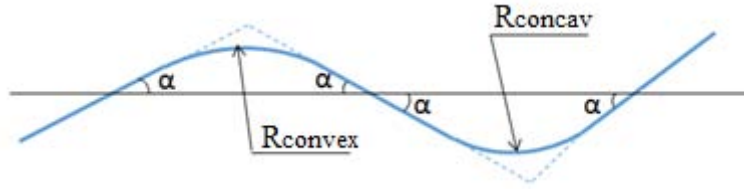


Figure 2: Macrostructure of road profile sequence

Depending on the mentioned macrostructures whose design speeds are in the range 25 km/h - 120 km/h, there were defined eight road profiles, with the following characteristics:

Table 1: Macrostructure of road profile

Road profile speed [km/h]	$\alpha$ [°]	$R_{convex}$ [m]	$R_{concaV}$ [m]
25	8	500	300
30	7,5	800	500
40	7	1000	1000
50	7	1300	1000
60	6,5	1600	1500
80	6	4500	2200
100	5	10000	3000
120	5	18000	6500

Following the conditions from the table 1, it results a sequence of road characteristics used in simulation:

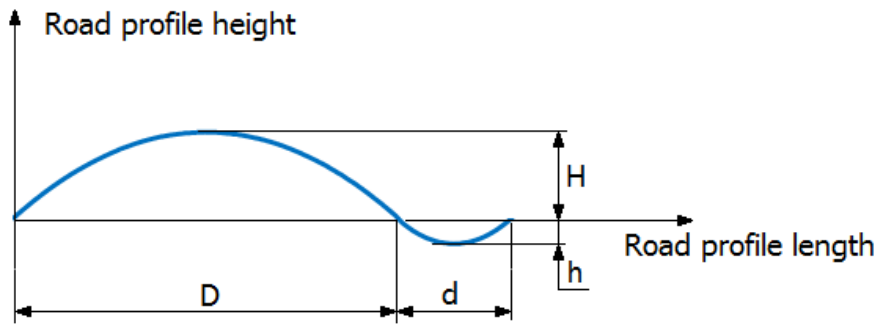


Figure 3: Characteristics of macrostructure road profile sequence

Table 2: Characteristics of macrostructure road profile

Road profile speed [km/h]	H [m]	h [m]	D [m]	d [m]
25	1.6	0.9	80	48
30	2.2	1.4	120	75
40	2.4	2.4	140	140
50	3.1	2.4	181	140
60	3.3	3.2	207	196
80	8.1	3.9	538	224
100	7.1	2.1	748	263
120	12.2	4.5	1330	480

The road profile sequences with a concave and convex radius, will be repeated until the length of road, in horizontally profile, will have the value of 1 km (distance used in simulation).

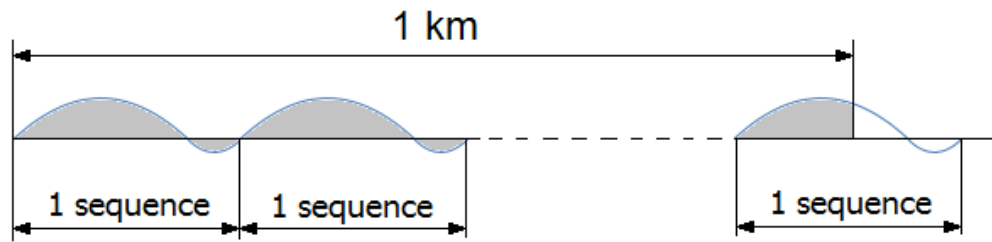


Figure 4: Road profiling of macrostructures sequences

The road profiles used in the simulation consists of overlapping macrostructures and microstructures. Thus, a combination of 27 profiles road results. Due to passenger's discomfort caused by strong vibrations, the ISO profile B-C, C-D and D-E will not be subject of the simulation in high speeds area.

Table 3: The road profiles used in simulation

120 km/h				
100 km/h				
80 km/h				
60 km/h				
50 km/h				
40 km/h				
30 km/h				
25 km/h				
	ISO A-B	ISO B-C	ISO C-D	ISO D-E

### III. THE CAR PARAMETERS

Parameters used in the car simulation have been chosen as the average values of middle-class cars:

- unladed weight:  $m_0 = 1100 \text{ kg}$ ;
- total weight:  $m_a = 1600 \text{ kg}$ ;
- wheelbase:  $L = 2600 \text{ mm}$ ;
- the distance  $a_0 = 1170\text{mm}$ ;
- the distance  $b_0 = 1430\text{mm}$ ;
- the distance  $a_1 = 1430\text{mm}$ ;
- the distance  $b_1 = 1170\text{mm}$ ;
- the ratio  $a_0 / L = 0.45$ ;
- the ratio  $b_0 / L = 0.55$ ;
- the ratio  $a_1 / L = 0.55$ ;
- the ratio  $b_1 / L = 0.45$ ;

where:

- $a_0$  is the distance between the center of the front axle and the mass center of the vehicle, horizontally measured, considering only the car's unladed weight;
- $b_0$  is the distance between the center of the rear axle and the mass center of the vehicle, horizontally measured, considering only the car's unladed weight;
- $a_1$  is the distance between the center of the front axle and the mass center of the vehicle, horizontally measured, considering the total weight of car;

- $b_1$  is the distance between the center of the rear axle and the mass center of the vehicle, horizontally measured, considering the total weight of car;

### IV. THE SUSPENSION PARAMETERS

Vehicle suspensions used in the simulation have the following characteristics:

- unsprung mass, corresponding to the front axle,  $m_{s1} = 46 \text{ kg}$ , [3][4];
- unsprung mass, corresponding to the rear axle,  $m_{s2} = 46 \text{ kg}$ , [3][4];
- sprung mass, corresponding to the front axle (for unladed car weight),  $m_1 = 605 \text{ kg}$ ;
- sprung mass, corresponding to the rear axle (for unladed car weight),  $m_2 = 495 \text{ kg}$ ;
- sprung mass, corresponding to the front axle (for total car mass),  $m_{a1} = 720 \text{ kg}$ ;
- sprung mass, corresponding to the rear axle (for total car mass),  $m_{a2} = 880 \text{ kg}$ ;
- front suspension spring rate (for one spring):  $k_{s1} = 23929 \text{ N/m}$ , [5];
- rear suspension spring rate (for one spring):  $k_{s2} = 28500 \text{ N/m}$ , [5];
- front suspension damping (for one damper):  $c_{s1} = 1712 \text{ N}\cdot\text{s/m}$ , [6];
- rear suspension damping (for one damper):  $c_{s2} = 1725 \text{ N}\cdot\text{s/m}$ , [6];
- tire stiffness front axle (for one tire):  $k_{t1} = 165000 \text{ N/m}$ , [7];

- tire stiffness rear axle (for one tire):  $k_{t2} = 165000$  N/m, [7];
- tire damping front axle (for one tire):  $c_{t1} = 3430$  N-s/m, [8];
- tire damping rear axle (for one tire):  $c_{t2} = 3430$  N-s/m, [8];
- front suspension excitation:  $X_{r1}$  - depending on road profile;
- rear suspension excitation:  $X_{r2}$  - depending on road profile.

V. CONDITIONS OF SIMULATION

The conditions required for vehicle during the simulation are:

- simulation performed in two conditions, the car's unladed weight and with total weight;
- straight displacement at a constant speed;
- all the profiles road used in simulation have a length of 1 km;

- the cross profile of the road is symmetrical.

VI. SUSPENSION MATHEMATICAL MODEL

Each suspension vehicle consists of:

- the suspension itself;
- the tyres.

The suspension itself includes the springs, the dampers and the arms of the car body. Here it was defined the suspension mass ( $m_s$ ), vehicle sprung mass ( $m_1$ ), the suspension spring rate ( $k_s$ ) and the suspension damping ( $c_s$ ).The tire was defined as an independent suspension with the same elements, spring and damper. It was considered the tire stiffness ( $k_t$ ) and tire damping ( $c_t$ ).The suspension excitation is characteristic for every road profile ( $X_r$ ) and is identical between the front and rear axle, but out of phase with the length of the wheelbase.

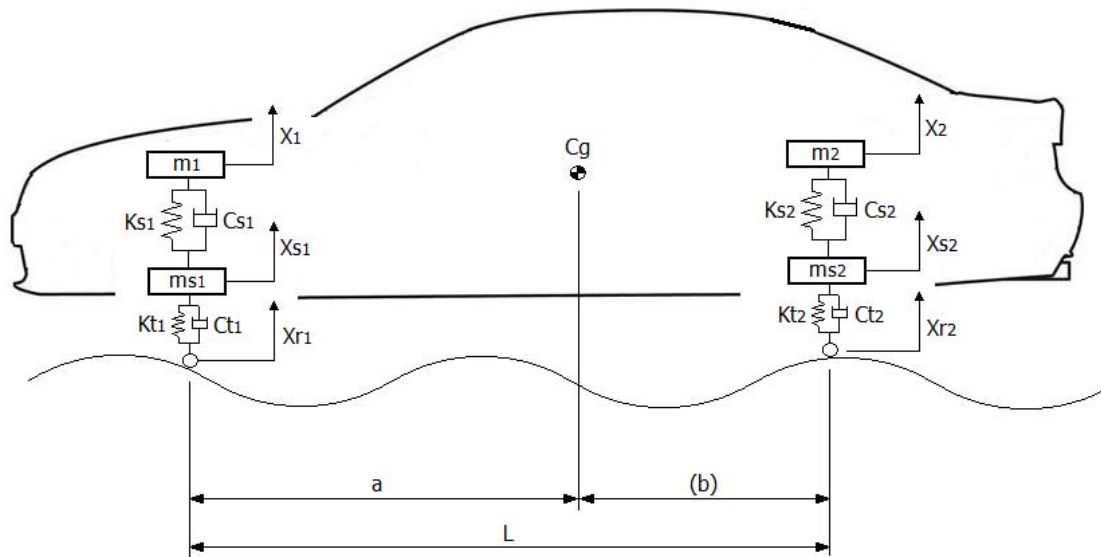


Figure 5: The suspension model

The mathematical model includes the entire vehicle, the suspension of front and rear axle, [9].

$$m_1 \ddot{x}_1 - c_{s1}(\dot{x}_1 - \dot{x}_{s1}) - k_{s1}(x_1 - x_{s1}) = 0 \tag{1.a}$$

$$m_{s1} \ddot{x}_{s1} + c_{s1}(\dot{x}_1 - \dot{x}_{s1}) + k_{s1}(x_1 - x_{s1}) - c_{t1}(\dot{x}_{s1} - \dot{x}_{r1}) - k_{t1}(x_{s1} - x_{r1}) = 0 \tag{1.b}$$

$$m_2 \ddot{x}_2 - c_{s2}(\dot{x}_2 - \dot{x}_{s2}) - k_{s2}(x_2 - x_{s2}) = 0 \tag{2.a}$$

$$m_{s2} \ddot{x}_{s2} + c_{s2}(\dot{x}_2 - \dot{x}_{s2}) + k_{s2}(x_2 - x_{s2}) - c_{t2}(\dot{x}_{s2} - \dot{x}_{r2}) - k_{t2}(x_{s2} - x_{r2}) = 0 \tag{2.b}$$

The (1.a) and (1.b) formulas are applied to the front axle and the (2.a) and (2.b) formulas are applied to the rear axle. The figure 4 presents the MatLab Simulink model achieved for a single axle. The input data are: the sprung mass, corresponding to the front/rear axle, the

suspension weight and the road profile. Using these data, as well as operating parameters and the suspension of the car, it was determined the total energy dissipated by the respective axle shock absorbers.

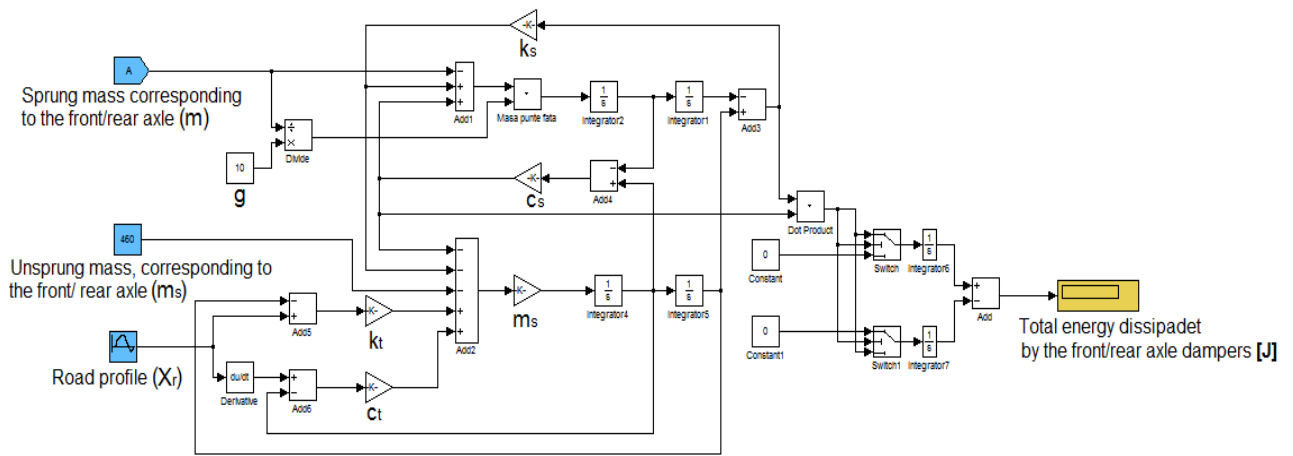


Figure 6: The suspension model used in MatLab Simulink

VII. RESULTS

For each road profile, the energies dissipated by the car suspensions were calculated. The values

obtained are represented in Tables no.4 and no.5, expressed in Joules.

Table 4: The dissipated energy by all the dampers, corresponding to unladed car weight

	ISO A-B	ISO B-C	ISO C-D	ISO D-E
25 km/h	8877	8011	8444	8852
30 km/h	8610	8491	9920	9905
40 km/h	6567	6151	8198	8519
50 km/h	6525	6322	7956	7905
60 km/h	5914	5954	6755	8125
80 km/h	5351	5341	6290	6771
100 km/h	4222	3792	-	-
120 km/h	3062	-	-	-

Table 5: The dissipated energy by all the dampers, corresponding to total car weight

	ISO A-B	ISO B-C	ISO C-D	ISO D-E
25 km/h	13930	12380	14760	13650
30 km/h	13000	12730	15000	15490
40 km/h	9328	9577	12240	12880
50 km/h	9363	9482	11960	11670
60 km/h	8502	8339	9830	11300
80 km/h	7592	7323	8855	9553
100 km/h	5735	5449	-	-
120 km/h	4297	-	-	-

For a qualitative representation of dissipated energy by the dampers, in relation to the energy consumed by the car in order to cover the distance of 1 km, it is considered the car has tires rolling resistance coefficient  $f = 0.008$ , the drag coefficient  $c_x = 0.28$  and the frontal area  $A_x = 2 \text{ m}^2$ . The resistances who acts on

the car are: rolling resistance and aerodynamic drag. The results are presented in the figure 7 and figure 8.

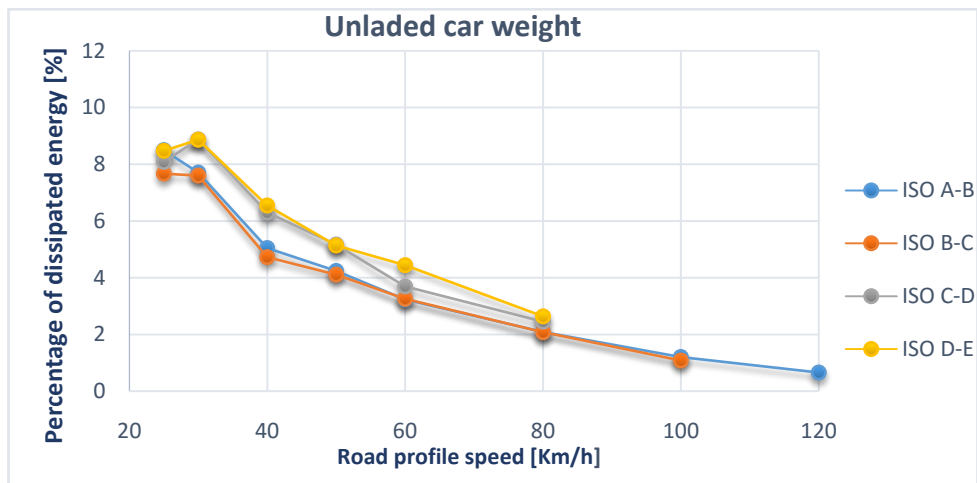


Figure 7: Percentage of energy dissipated by the dampers, in relation to the energy consumed by the engine car with unladen weight, to cover the distance of 1 km

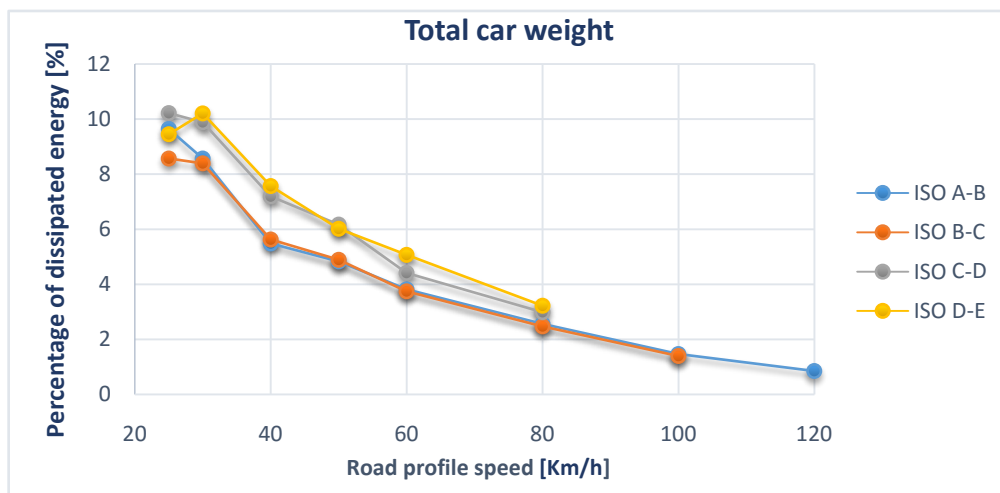


Figure 8: Percentage of energy dissipated by the dampers, in relation to the energy consumed by the engine car with total weight, to cover the distance of 1 km

## VIII. CONCLUSIONS

The simulation of system suspension shows a relation between the energy dissipated by the damping car and vehicle and road profile properties. Among the properties of the car, it results that the mass of the car ( $m$ ), the suspension spring ( $k_s$ ) and the suspension damping ( $c_s$ ) are the elements that influence the dissipated energy. An increase of mass vehicle and damping coefficient, corroborated with a decrease of spring rate, will produce a higher energy dissipation for the dampers. The road profile subcomponent who have the biggest influence on the suspension excitation is the microstructure. The macrostructure has an important role only if the road profile speeds is below 60 km/h. Thus, a car loaded, with elastic suspension and stiff dampers, will require to dissipate more energy through the dampers. However, macrostructure profiles of road categories with maximum speeds between 25 km/h - 60

km/h and microstructures profiles of road categories ISO C-D and ISO D-E contributes to increased suspension load.

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## Study on Simulation of on-Center Handling Tests

By Xiao-Feng Wang

*Tsinghua University*

**Abstract-** This paper describes a simulation of on-center handling test, in which a linear 3 degrees of freedom vehicle handling model and a power integral steering system model are incorporated to calculate the time histories of steering wheel angle, steering wheel torque, and vehicle lateral acceleration. The cross plots of steering wheel angle-lateral acceleration, steering wheel torque-lateral acceleration, steering wheel torque-steering wheel angle, steering work-lateral acceleration, and steering work gradient-lateral acceleration are drawn and all the on-center handling parameters are determined from them. The simulation results are compared with the data presented in the literatures, which indicates that the simulation results are reasonable.

**Keywords:** *on-center handling test; simulation; vehicle handling model; power steering system model; time history; steering wheel angle; steering wheel torque; lateral acceleration; cross plot.*

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# Study on Simulation of on-Center Handling Tests

Xiao-Feng Wang

**Abstract-** This paper describes a simulation of on-center handling test, in which a linear 3 degrees of freedom vehicle handling model and a power integral steering system model are incorporated to calculate the time histories of steering wheel angle, steering wheel torque, and vehicle lateral acceleration. The cross plots of steering wheel angle-lateral acceleration, steering wheel torque-lateral acceleration, steering wheel torque-steering wheel angle, steering work-lateral acceleration, and steering work gradient-lateral acceleration are drawn and all the on-center handling parameters are determined from them. The simulation results are compared with the data presented in the literatures, which indicates that the simulation results are reasonable.

**Keywords:** on-center handling test; simulation; vehicle handling model; power steering system model; time history; steering wheel angle; steering wheel torque; lateral acceleration; cross plot.

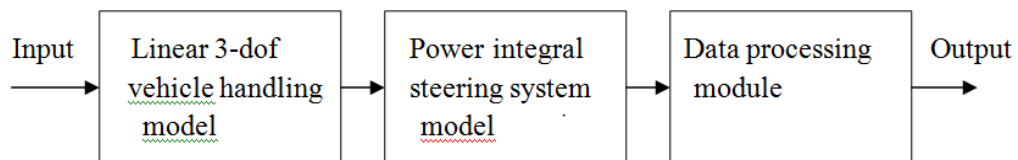
## I. INTRODUCTION

Norman (1984) described how to do on-center handling test in detail. On-center handling test has been widely used to measure handling characteristics observed by a car driver during normal highway and freeway driving. It is also one of the essential tests used by car and its steering system manufacturers to quantify the performance of steering systems. The simulation of on-center handling test can help them determine the appropriate system parameters

combination to make a car have good on-center handling characteristics.

There have been some papers published, in which the methods for simulating on-center handling tests are introduced. Post et al. (1996) and Kim (1997) described different simulation methods but they didn't present all the on-center handling cross plots and determine all the on-center handling parameters necessary for characterizing vehicle's on-center handling performance prescribed by Norman (1984).

This paper describes a simulation of on-center handling test, which is based on the test procedure presented by Norman (1984). A linear 3-dof (degrees of freedom) vehicle handling model and a power integral steering system model are incorporated to calculate the time histories of steering wheel angle, steering wheel torque, and vehicle lateral acceleration. The cross plots of steering wheel angle-lateral acceleration, steering wheel torque-lateral acceleration, steering wheel torque-steering wheel angle, steering work-lateral acceleration, and steering work gradient-lateral acceleration are drawn and all the on-center handling parameters are determined from them. Fig.1 shows the main modules of the simulation program.



*Input:* reference steer angle of vehicle front wheels

*Output:* on-center handling cross plots and parameters

Fig. 1: Main modules of the simulation program

## II. 3-DOF VEHICLE HANDLING MODEL

A linear 3-dof vehicle handling model is adopted in the simulation because the peak lateral acceleration is limited to about 0.2g in the on-center handling tests as prescribed by Norman (1984). This

kind of model can give sufficiently accurate simulation Results in such low lateral acceleration range. Fig.2 shows the model. In the model, SAE vehicle and tire axis systems are applied. The three degrees of freedom are

yaw velocity  $r$ , sideslip angle  $\beta$ , and roll angle  $\phi$ . The model is constructed based on the papers by Nedley et al (1972) and Riede et al (1984). The basic equations for the vehicle model are:

$$\alpha_f = \frac{u \cdot \beta + a \cdot r}{u} + \delta_s - \delta_{ref} \quad (1)$$

$$\alpha_r = \frac{u \cdot \beta - b \cdot r}{u} - \delta_r \quad (2)$$

$$F_{y1} = -2 \cdot C_{\alpha f} \cdot \alpha_f + 2 \cdot C_{\gamma f} \cdot \gamma_f \quad (3)$$

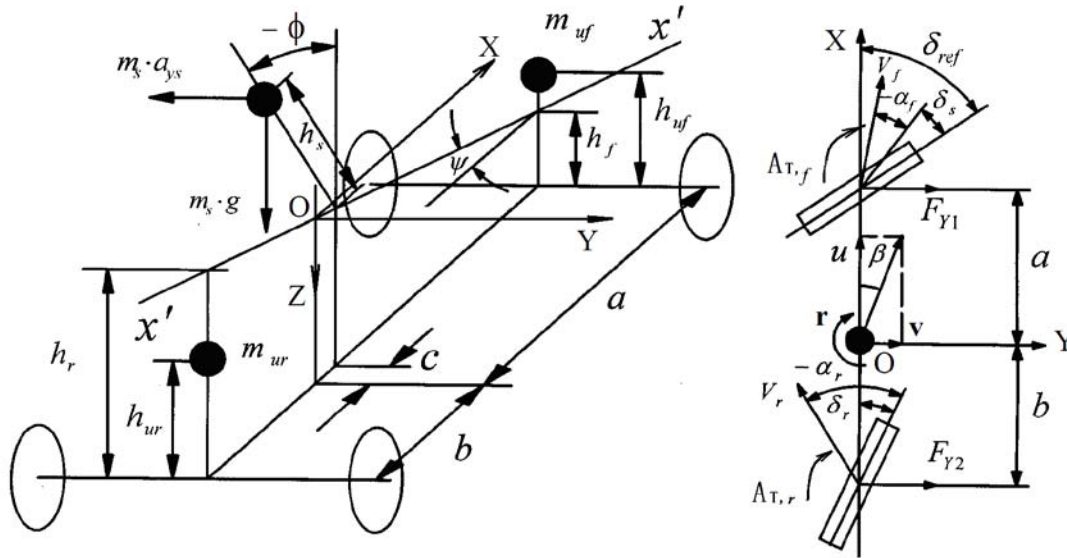


Fig. 2: Linear 3-dof vehicle handling model

$$F_{y2} = -2 \cdot C_{\alpha r} \cdot \alpha_r + 2 \cdot C_{\gamma r} \cdot \gamma_r \quad (4)$$

$$\delta_s = -E_{\phi f} \cdot \phi + E_{y f} \cdot \frac{F_{y1} - m_{uf} \cdot (u \cdot \dot{\beta} + a \cdot \dot{r} + u \cdot r)}{2} - E_{\delta f} \cdot \frac{A_{T,f}}{2} \quad (5)$$

$$A_{T,f} = 2 \cdot N_{\alpha f} \cdot \alpha_f + 2 \cdot N_{\gamma f} \cdot \gamma_f \quad (6)$$

$$\gamma_f = \Gamma_{\phi f} \cdot \phi - \Gamma_{y f} \cdot \frac{F_{y1} - m_{uf} \cdot (u \cdot \dot{\beta} + a \cdot \dot{r} + u \cdot r)}{2} + \Gamma_{\delta f} \cdot \frac{A_{T,f}}{2} \quad (7)$$

$$\delta_r = -E_{\phi r} \cdot \phi + E_{y r} \cdot \frac{F_{y2} - m_{ur} \cdot (u \cdot \dot{\beta} - b \cdot \dot{r} + u \cdot r)}{2} - E_{\delta r} \cdot \frac{A_{T,r}}{2} \quad (8)$$

$$A_{T,r} = 2 \cdot N_{\alpha r} \cdot \alpha_r + 2 \cdot N_{\gamma r} \cdot \gamma_r \quad (9)$$

$$\gamma_r = -\Gamma_{\phi r} \cdot \phi + \Gamma_{y r} \cdot \frac{F_{y2} - m_{ur} \cdot (u \cdot \dot{\beta} - b \cdot \dot{r} + u \cdot r)}{2} - \Gamma_{\delta r} \cdot \frac{A_{T,r}}{2} \quad (10)$$

where,  $\alpha_f$ ,  $\alpha_r$  - front, rear tire slip angle;  $u$  - vehicle forward speed;  $a$ ,  $b$  - distance from vehicle center of

gravity to front, rear wheel centerline;  $\delta_s$ ,  $\delta_r$  - front, rear wheel compliance steer angle;  $F_{y1}$ ,  $F_{y2}$  - front, rear tires

rear tires lateral force;  $C_{\alpha f}$ ,  $C_{\alpha r}$  - front, rear tire cornering stiffness;  $\gamma_f$ ,  $\gamma_r$  - front, rear tire inclination angle;  $C_{\gamma f}$ ,  $C_{\gamma r}$  - front, rear tire camber stiffness;  $E_{\phi f}$ ,  $E_{\phi r}$  - front, rear roll steer coefficient;  $E_{\gamma f}$ ,  $E_{\gamma r}$  - front, rear lateral force compliance steer coefficient;  $E_{\tau f}$ ,  $E_{\tau r}$  - front, rear aligning torque compliance steer coefficient;  $m_{uf}$ ,  $m_{ur}$  - front, rear unsprung mass;  $A_{Tf}$ ,  $A_{Tr}$  - front, rear tires aligning torque;  $N_{\alpha f}$ ,  $N_{\alpha r}$  - front, rear tire aligning torque stiffness;  $N_{\gamma f}$ ,  $N_{\gamma r}$  - front, rear tire aligning torque stiffness due to camber;  $\Gamma_{\phi f}$ ,  $\Gamma_{\phi r}$  - front, rear roll camber coefficient;  $\Gamma_{\gamma f}$ ,  $\Gamma_{\gamma r}$  - front, rear lateral force compliance camber

coefficient;  $\Gamma_{\tau f}$ ,  $\Gamma_{\tau r}$  - front, rear aligning torque compliance camber coefficient;  $h_f$ ,  $h_r$  - front, rear roll center height;  $h_{uf}$ ,  $h_{ur}$  - front, rear unsprung center of gravity height;  $m_s$  - vehicle sprung mass;  $\psi$  - roll axis inclination in side view;  $h_s$  - distance from sprung center of gravity to roll axis;  $K_{\phi f}$ ,  $K_{\phi r}$  - front, rear suspension roll stiffness;  $C_{\phi f}$ ,  $C_{\phi r}$  - front, rear suspension roll damping;  $a_{ys}$  - lateral acceleration of sprung center of gravity. The equations of motion for the vehicle model are derived as follows, in which  $\psi$  is assumed to be zero for simplicity because it's usually small:

$$m_a \cdot (u \cdot \dot{\beta} + u \cdot r) + m_s \cdot h_s \cdot \ddot{\phi} = F_{y1} + F_{y2} \tag{11}$$

$$I_z \cdot \dot{r} - I_{xzs} \cdot \ddot{\phi} = a \cdot F_{y1} - b \cdot F_{y2} + A_{T,f} + A_{T,r} \tag{12}$$

$$I_{xs} \cdot \ddot{\phi} - I_{xzs} \cdot \dot{r} + m_s \cdot h_s \cdot u \cdot (\dot{\beta} + r) = (m_s \cdot g \cdot h_s - K_{\phi f} - K_{\phi r}) \cdot \phi - (C_{\phi f} + C_{\phi r}) \cdot \dot{\phi} \tag{13}$$

where,  $m_a$  - vehicle total mass;  $I_z$  - vehicle total yaw inertia;  $I_{xzs}$  - sprung roll-yaw product;  $I_{xs}$  - sprung roll inertia;  $g$  - gravitational acceleration.

Table 1 shows the values of the vehicle model parameters used in the simulation.

Table 1: Values of the vehicle model parameters used in the simulation

$u = 100\text{km/h}$ - vehicle forward speed
$C_{\alpha f} = 1608.5 \text{ N/deg}$ , $C_{\alpha r} = 1391.4 \text{ N/deg}$ - front, rear tire cornering stiffness
$C_{\gamma f} = 46.3 \text{ N/deg}$ , $C_{\gamma r} = 38.8 \text{ N/deg}$ - front, rear tire camber stiffness
$N_{\alpha f} = 45 \text{ Nm/deg}$ , $N_{\alpha r} = 32.6 \text{ Nm/deg}$ - front, rear tire aligning torque stiffness
$N_{\gamma f} = 0.0 \text{ Nm/deg}$ , $N_{\gamma r} = 0.0 \text{ Nm/deg}$ - front, rear tire aligning torque stiffness due to camber
$E_{\phi f} = -0.17 \text{ deg/deg}$ , $E_{\phi r} = 0.08 \text{ deg/deg}$ - front, rear roll steer coefficient
$E_{\gamma f} = 0.28 \text{ deg/kN}$ , $E_{\gamma r} = -0.01 \text{ deg/kN}$ - front, rear lateral force compliance steer coefficient
$E_{\tau f} = 1.1 \text{ deg/hNm}$ , $E_{\tau r} = -0.14 \text{ deg/hNm}$ - front, rear aligning torque compliance steer coefficient
$\Gamma_{\phi f} = 0.65 \text{ deg/deg}$ , $\Gamma_{\phi r} = -0.1 \text{ deg/deg}$ - front, rear roll camber coefficient
$\Gamma_{\gamma f} = 0.25 \text{ deg/kN}$ , $\Gamma_{\gamma r} = -0.4 \text{ deg/kN}$ - front, rear lateral force compliance camber coefficient
$\Gamma_{\tau f} = 0.07 \text{ deg/hNm}$ , $\Gamma_{\tau r} = 0.01 \text{ deg/hNm}$ - front, rear aligning torque compliance camber coefficient;
$K_{\phi f} = 1303 \text{ Nm/deg}$ , $K_{\phi r} = 730 \text{ Nm/deg}$ - front, rear suspension roll stiffness
$C_{\phi f} = 40 \text{ Nm/(deg/s)}$ , $C_{\phi r} = 40 \text{ Nm/(deg/s)}$ - front, rear suspension roll damping
$m_a = 1702 \text{ kg}$ - vehicle total mass
$m_{uf} = 95 \text{ kg}$ , $m_{ur} = 132 \text{ kg}$ - front, rear unsprung mass
$m_s = 1475 \text{ kg}$ - vehicle sprung mass
$I_z = 3377.3 \text{ kg-m}^2$ - vehicle total yaw inertia
$I_{xzs} = -28.1 \text{ kg-m}^2$ - sprung roll-yaw product
$I_{xs} = 598.8 \text{ kg-m}^2$ - sprung roll inertia;
$a = 1170.8 \text{ mm}$ , $b = 1397.2 \text{ mm}$ - distance from vehicle center of gravity to front, rear wheel centerline
$c = 49.6 \text{ mm}$ - distance from sprung center of gravity to vehicle center of gravity
$h_f = 57 \text{ mm}$ , $h_r = 194 \text{ mm}$ - front, rear roll center height
$h_{uf} = 305 \text{ mm}$ , $h_{ur} = 310 \text{ mm}$ - front, rear unsprung center of gravity height
$h = 477 \text{ mm}$ - vehicle total center of gravity height
$h_s = 385.11 \text{ mm}$ - distance from sprung center of gravity to roll axis;

Let

$$Z_\phi = \dot{\phi} \tag{14}$$

$$U = [r, \beta, \phi, Z_\phi]^T \tag{15}$$

$$\dot{U} = [r, \dot{\beta}, \dot{\phi}, \dot{Z}_\phi]^T \quad (16)$$

The equations (11), (12), and (13) can be written in the matrix form with  $\delta_{ref}$  as the input:

$$M \cdot \dot{U} = R \cdot U + N \cdot \delta_{ref} \quad (17)$$

where,  $M, R$ -  $4 \times 4$  matrix;  $N$ -  $4 \times 1$  matrix.

Equation (17) is changed into equation (18) by multiplying  $M^{-1}$  on both sides of it:

$$\dot{U} = M^{-1} \cdot R \cdot U + M^{-1} \cdot N \cdot \delta_{ref} \quad (18)$$

Equation (18) is solved with Runge-Kutta numerical integration method. In the simulation, the formula of  $\delta_{ref}$  is

$$\delta_{ref} = \delta_{refA} \cdot \sin(2 \cdot \pi \cdot f_H \cdot t) \quad (19)$$

where,  $\delta_{refA}$  - amplitude of  $\delta_{ref}$ ;  $f_H$  - frequency. Fig.3(a) shows the time history of  $\delta_{ref}$  in which  $\delta_{refA} = 0.86$  deg and  $f_H = 0.5$  Hz. Fig.3 (b) shows the corresponding time history of yaw velocity  $r$ . And the lateral acceleration  $a_y$  is calculated as the product of vehicle speed  $u$  and yaw velocity  $r$  for easy measurement as prescribed by Norman (1984).

$$a_y = r \cdot u \quad (20)$$

Fig.3(c), (d) show the time histories of  $F_{y1}$ ,  $A_{Tf}$ , respectively.

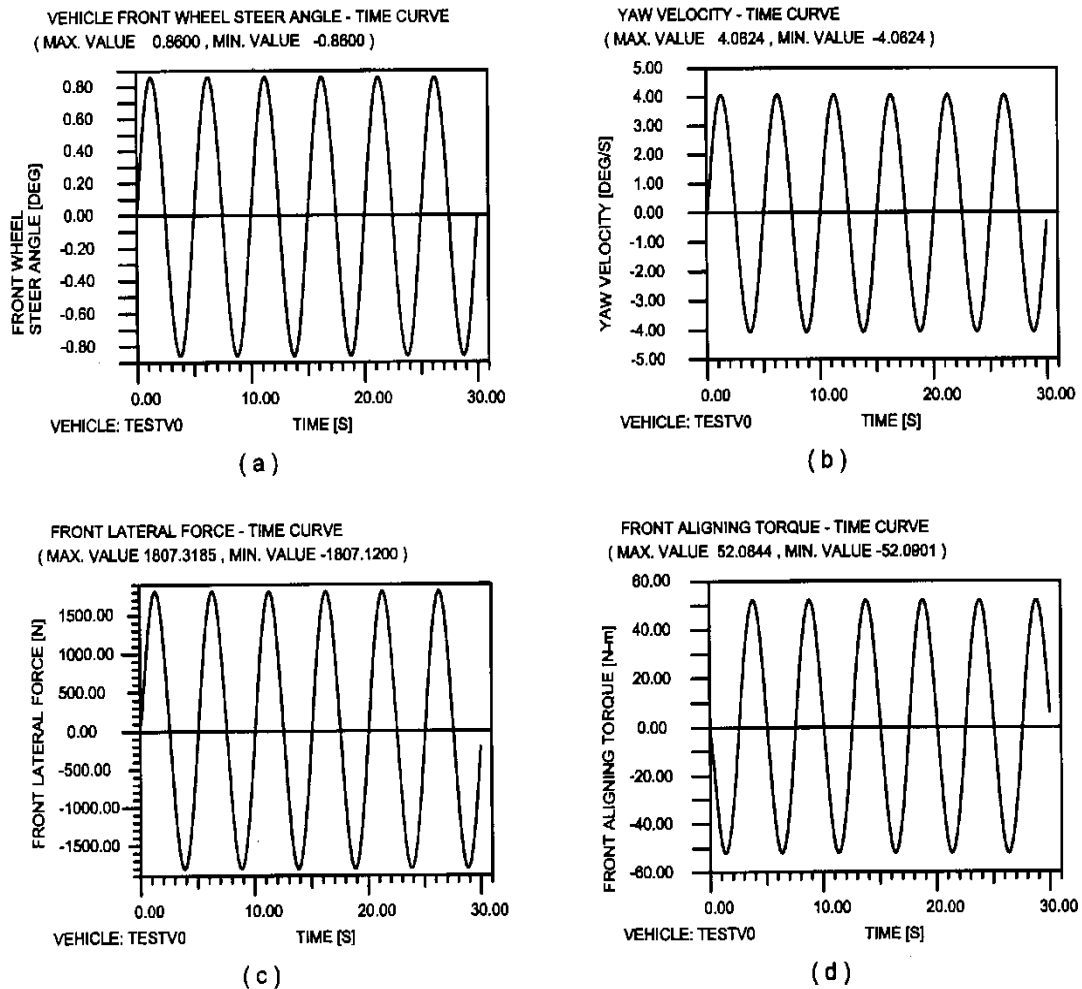


Fig. 3: Input and some response histories of the Linear 3-dof vehicle handling model

In order to obtain the on-center handling characteristics, the steering wheel rotation angle and torque have to be determined. A model of the steering system is constructed to determine them.

### III. MODEL OF THE STEERING SYSTEM

It is assumed that the vehicle studied is a rear drive vehicle equipped with a power integral steering gear and the inertia forces and moments of all parts in the steering system can be neglected. Fig. 4 shows the

model of the steering system. The formula for the kingpin aligning torque  $A_{T,k}$  is

$$A_{T,k} = A_{T,f} \cdot \cos \tau \cdot \cos \sigma' - r_d \cdot \sin \tau \cdot \cos \sigma' \cdot F_{y1} - W_f \cdot r_n \cdot \cos \tau \cdot \sin \sigma' \cdot \delta_{ref} \tag{21}$$

$$\sigma' = \arctg(tg \sigma \cdot \cos \tau) \tag{22}$$

$$r_n = (r_d \cdot tg \sigma + r_s) \cdot \cos \sigma' \tag{23}$$

where,  $\tau$  – caster;  $\sigma$  – kingpin inclination angle;  $r_s$  – kingpin off-set;  $r_d$  – radius of front tire;  $W_f$  – vertical load on front axle; camber is assumed to be zero.

Fig. 5 shows the section view of the valve body and valve spool in their assembled position as well as the valve equivalent flow paths.

When the vehicle's engine is running, the flow  $Q_T$  from the power steering pump gets into the four axial supply grooves F on the inside diameter of the valve body through the four supply holes E. Then, the flow diverts into two parts,  $Q_L$  and  $Q_R$ :

1) The flow  $Q_L$  flows to the left and gets into the four

axial grooves  $G_{L1}$  on the outside diameter of the spool through the valve gaps  $B_1$ . This flow again diverts into two parts,  $Q_B$  flowing into the power cylinder and  $(Q_L - Q_B)$  getting into the four axial grooves  $G_{L2}$  on the inside diameter of the valve body through the valve gaps  $B_2$  and further flowing into the center of the spool through the return holes in the spool. The center of the spool is freely communicated to the power steering reservoir and is a low pressure zone.

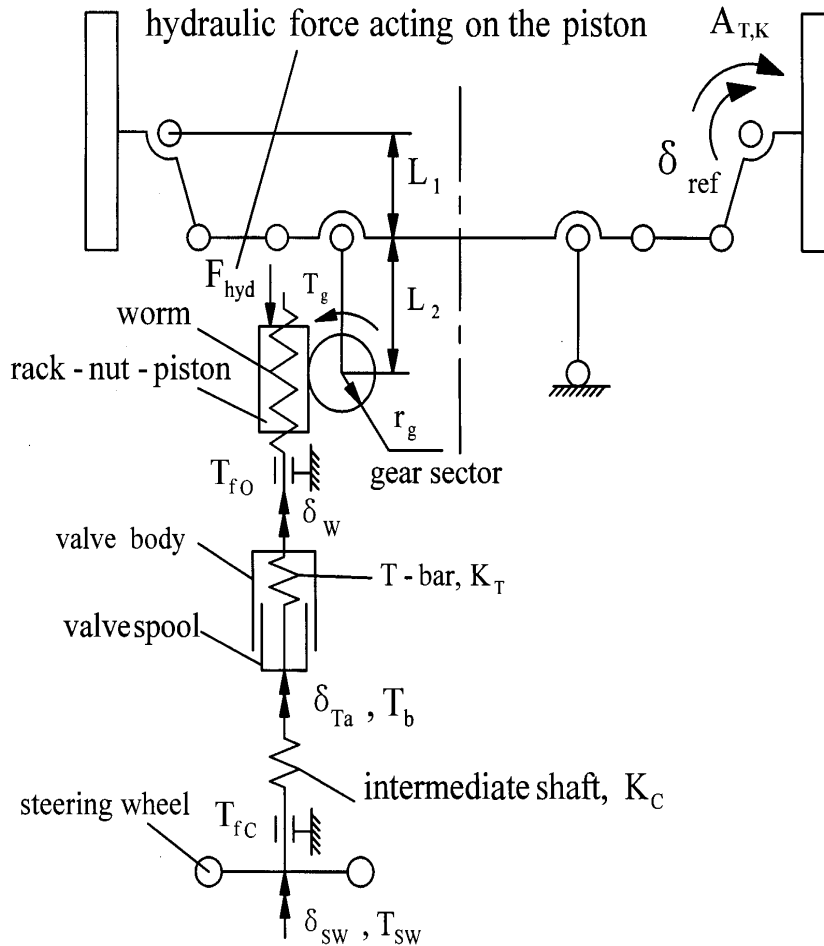


Fig. 4: Model of the integral power steering system

2) The flow  $Q_R$  flows to the right and gets into the four axial grooves  $G_{R1}$  on the outside diameter of the spool through the valve gaps  $A_1$  and is combined with the flow  $Q_A$  from the cylinder. The combined

flow  $(Q_R + Q_A)$  gets into the four axial grooves  $G_{R2}$  on the inside diameter of the valve body through the valve gaps  $A_2$  and further flows into the center of the spool through the return holes in the spool.



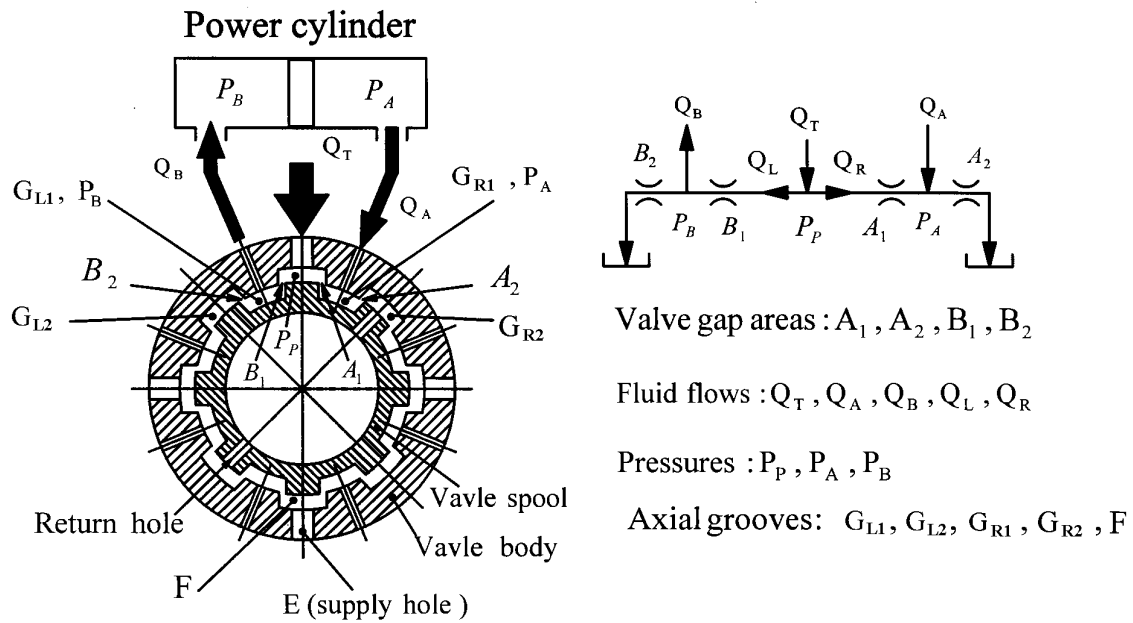


Fig. 5: Section view of the valve body and valve spool in their assembled position as well as the valve equivalent flow paths

The valve spool rotates relative to the valve body as the T-bar (Torsion-bar) is twisted by the torque applied to it, causing the valve gaps  $A_1$ ,  $A_2$ ,  $B_1$ , and  $B_2$  to change. The basic valve equations are:

$$Q_R = C_q \cdot A_1 \cdot \sqrt{\frac{2 \cdot (P_P - P_A)}{\rho}} \quad (24)$$

$$Q_A + Q_R = C_q \cdot A_2 \cdot \sqrt{\frac{2 \cdot P_A}{\rho}} \quad (25)$$

$$Q_L = C_q \cdot B_1 \cdot \sqrt{\frac{2 \cdot (P_P - P_B)}{\rho}} \quad (26)$$

$$Q_L - Q_B = C_q \cdot B_2 \cdot \sqrt{\frac{2 \cdot P_B}{\rho}} \quad (27)$$

$$Q_T = Q_L + Q_R \quad (28)$$

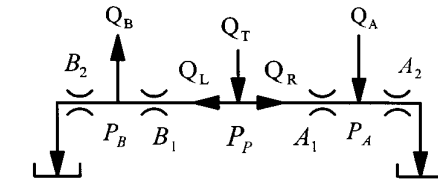
$$Q_A = Q_B \quad (29)$$

where, the pressure at the center of the spool is assumed to be zero; the leakage in the gear is neglected;  $P_P$  – pump pressure;  $P_A$ ,  $P_B$  – pressure at the groove  $G_{R1}$ ,  $G_{L1}$ ;  $C_q$  – flow coefficient of the valve gaps;  $\rho$  – fluid density.

A power integral steering gear was taken apart and its valve geometry was measured. Fig. 6(a) shows the areas of  $A_1$ ,  $A_2$ ,  $B_1$ , and  $B_2$  versus the rotational angle of the spool relative to the valve body.

Let  $P_{DIFF}$  be the pressure differential across the cylinder piston, thus

$$P_{DIFF} = P_B - P_A \quad (30)$$



Valve gap areas :  $A_1, A_2, B_1, B_2$

Fluid flows :  $Q_T, Q_A, Q_B, Q_L, Q_R$

Pressures :  $P_P, P_A, P_B$

Axial grooves :  $G_{L1}, G_{L2}, G_{R1}, G_{R2}, F$

Fig. 6(b) shows the pressure differential  $P_{DIFF}$  versus spool rotation angle relative to the valve body. It can be seen that  $Q_A, Q_B$  (flows from and to the power cylinder) have effect on  $P_{DIFF}$ .  $P_{DIFF}$  decreases as  $Q_A$  increases and vice versa, with the spool rotation angle kept constant.

Let the ratio of steering linkage be  $R_{lnk}$ ,

$$R_{lnk} = \frac{L_1}{L_2} \quad (31)$$

The steering gear applies a torque  $T_g$  to balance  $A_{T,k}$ ,

$$T_g = -\frac{A_{T,k}}{R_{lnk}} \quad (32)$$

Let the over-center turning torque of the integral steering gear be  $T_{fo}$  when  $T_g$  is zero and the steering ratio of the gear be  $G_R$ .  $T_{fo}$  is assumed to be a dry friction torque. It can be equivalent to a dry friction torque  $T_{fg}$  acting on the gear sector,

$$T_{fg} = G_R \cdot T_{fo} \quad (33)$$

The net torque  $T_{gn}$  provided by driver's hand and hydraulic assist to the gear sector is

$$T_{gn} = T_g + s_n \cdot T_{fg} \quad (34)$$

$$s_n = \begin{cases} +1 & \text{when } \Delta\delta_{ref} \geq 0 \\ -1 & \text{when } \Delta\delta_{ref} < 0 \end{cases} \quad (35)$$

Let the torsional rate of the T-bar be  $K_T$ , its torsional angle be  $\delta_T$ , and the hydraulic cylinder efficiency be  $\eta_{hyd}$ . When  $\Delta\delta_{ref}$  has the same sign as  $T_{gn}$ , the torque  $T_{gn}$  forces the front wheels to turn. In this case,

$$(K_T \cdot \delta_T) \cdot GR + P_{DIFF} \cdot A_p \cdot r_g \cdot \eta_{hyd} = T_{gn} \quad (36)$$

where,  $P_{DIFF}$  - pressure differential across the hydraulic piston;  $A_p$  - area of the hydraulic cylinder;  $r_g$  -

pitch radius of the gear sector. The equation (36) can be written as

$$S_{11} \cdot \delta_T + S_{12} \cdot P_{DIFF} = S_{13} \quad (37)$$

where,

$$S_{11} = K_T \cdot G_R \quad (38)$$

$$S_{12} = A_p \cdot r_g \cdot \eta_{hyd} \quad (39)$$

$$S_{13} = T_{gn} \quad (40)$$

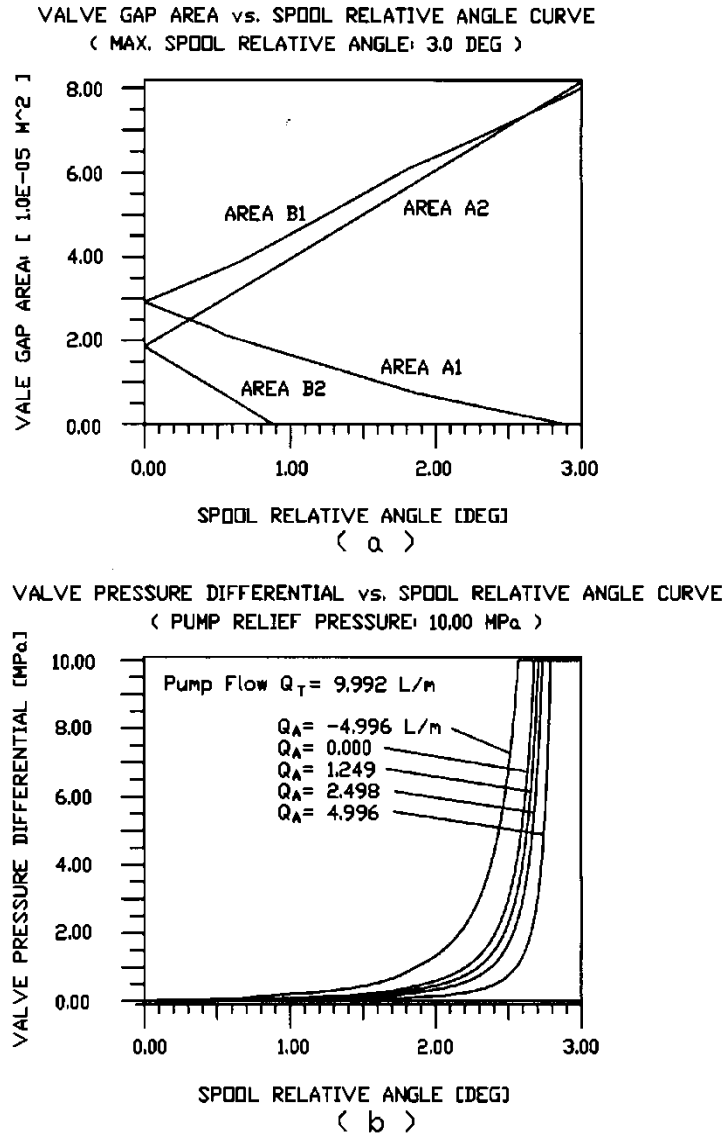


Fig. 6: Valve areas and pressure differential characteristics

When  $\Delta\delta_{ref}$  has different sign from  $T_{gn}$ , the torque  $T_{gn}$  resists the rotation of front wheels. In this case,

$$(K_T \cdot \delta_T) \cdot G_R + P_{DIFF} \cdot A_p \cdot r_g / \eta_{hyd} = T_{gn} \quad (41)$$

The equation (41) can be written as

$$S_{21} \cdot \delta_T + S_{22} \cdot P_{DIFF} = S_{23} \quad (42)$$

where,

$$S_{21} = K_T \cdot G_R \quad (43)$$

$$S_{22} = A_p \cdot r_g / \eta_{hyd} \quad (44)$$

$$S_{23} = T_{gn} \quad (45)$$

So, the equations (37) and (42) can be written as a general form,

$$S_1 \cdot \delta_T + S_2 \cdot P_{DIFF} = S_3 \quad (46)$$

Because  $\delta_T$  and  $P_{DIFF}$  always have the same sign as  $S_3$ , the equation (46) can be written as

$$S_1 \cdot |\delta_T| + S_2 \cdot |P_{DIFF}| = |S_3| \quad (47)$$

$$s_{np} = \begin{cases} +1 & \text{when } V_p \text{ has the same sign as } S_3. \\ -1 & \text{when } V_p \text{ has different sign from } S_3. \end{cases} \quad (51)$$

$$A_p = \frac{\pi \cdot D_p^2}{4} \quad (52)$$

where,  $D_p$  - diameter of the power cylinder.

As shown in Fig. 7, the straight line intersects with the pressure differential versus spool rotation angle

$$s_{ns} = \begin{cases} +1 & \text{when } S_3 \geq 0. \\ -1 & \text{when } S_3 < 0. \end{cases} \quad (48)$$

Let  $|\delta_T|$  and  $|P_{DIFF}|$  be the independent variables, equation (47) is a straight line in Fig. 7, which is obtained by putting the straight line onto Fig. 6(b), the valve pressure differential versus spool relative rotation angle curves.

Let the piston velocity be  $V_p$  and the flow to the hydraulic cylinder be  $Q_A$ ,

$$V_p = \frac{d(\delta_{ref})}{dt} \cdot R_{lnk} \cdot r_g \quad (49)$$

$$Q_A = s_{np} \cdot |V_p| \cdot A_p \quad (50)$$

curve corresponding to  $Q_A$ , giving the solution  $|\delta_T|$  and  $|P_{DIFF}|$ , and

$$\delta_T = s_{ns} \cdot |\delta_T| \quad (53)$$

$$P_{DIFF} = s_{ns} \cdot |P_{DIFF}| \quad (54)$$

VALVE PRESSURE DIFFERENTIAL vs. SPOOL RELATIVE ANGLE CURVE  
( PUMP RELIEF PRESSURE: 10.00 MPa )

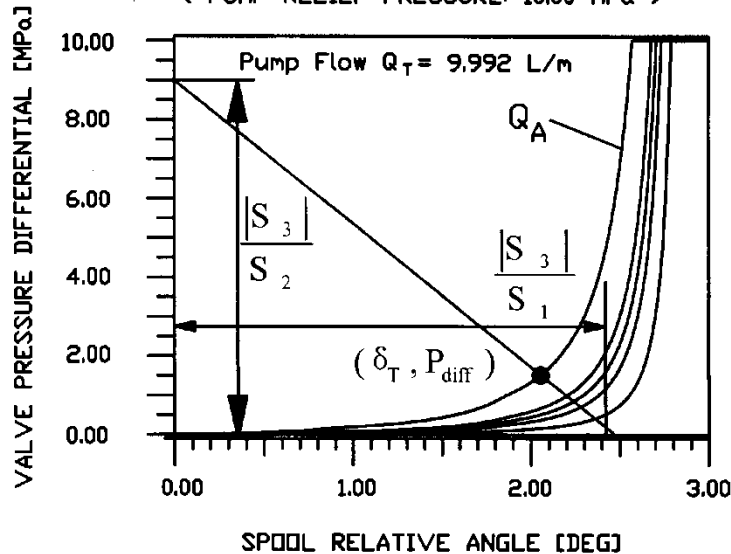


Fig. 7: Model for determining T-bar torsional angle and valve pressure differential

Let the absolute T-bar rotation angle be  $\delta_{Ta}$  and the T-bar torque be  $T_b$ ,

$$\delta_{Ta} = R_{lnk} \cdot \delta_{ref} \cdot G_R + \delta_T \quad (55)$$

$$T_b = K_T \cdot \delta_T \quad (56)$$

Let the torsional rate of the steering intermediate shaft be  $Kc$  and the dry friction of the steering column be  $T_{fc}$ ,

$$\delta_{sw} = \delta_{Ta} + T_b / K_c \tag{57}$$

$$T_{sw} = T_b + s_{mw} \cdot T_{fc} \tag{58}$$

$$s_{mw} = \begin{cases} +1 & \text{when } \Delta\delta_{sw} \geq 0. \\ -1 & \text{when } \Delta\delta_{sw} < 0. \end{cases} \tag{59}$$

where,  $\delta_{sw}$  - steering wheel rotation angle;  $T_{sw}$  - steering wheel torque.

Table 2 shows the values of the parameters used in the steering system model.

Fig. 8 shows the time histories of pressure differential  $P_{DIFF}$  and T-bar torsional angle  $\delta_T$ . Fig. 9 shows the time histories of  $\delta_{sw}$ ,  $T_{sw}$ , and lateral acceleration  $a_y(u \cdot r)$ .

Table 2: Values of the parameters used in the steering system model

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$\tau=5.0$ deg	- caster
$\sigma=12.0$ deg	- kingpin inclination angle
$r_s=20.0$ mm	- kingpin off-set
$r_d=302.0$ mm	- radius of front tire
$W_f=9260.0$ N	- vertical load on front axle
$Q_T=9.992$ L/m	- flow from the power steering pump to the steering gear
$C_q=0.7$	- flow coefficient of the valve gaps
$\rho=870$ kg/m <sup>3</sup>	- fluid density
$R_{lnk}=0.986$	- ratio of steering linkage
$T_{fo}=2.2$ Nm	- over-center turning torque of the integral steering gear
$G_R=14.0$	- steering ratio of the integral steering gear
$K_T=1.2$ Nm/deg	- torsional rate of the T-bar
$\eta_{hyd}=0.8$	- hydraulic cylinder efficiency
$D_p$	- diameter of the hydraulic cylinder
$r_g=33.33$ mm	- pitch radius of the pitman gear sector
$K_c=0.55$ Nm/deg	- torsional rate of the steering intermediate shaft
$T_{fc}=0.1$ Nm	- dry friction of the steering column

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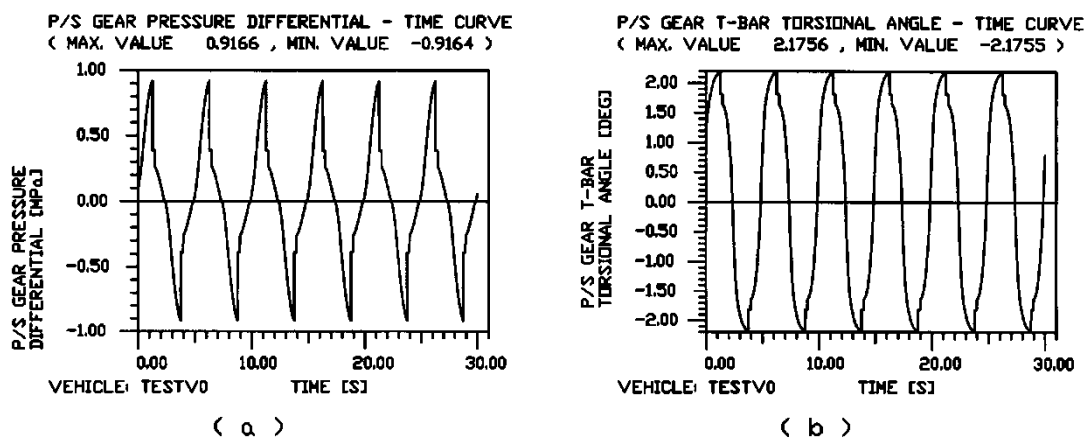


Fig. 8: Time histories of pressure differential  $P_{DIFF}$  and T-bar torsional angle  $\delta_T$

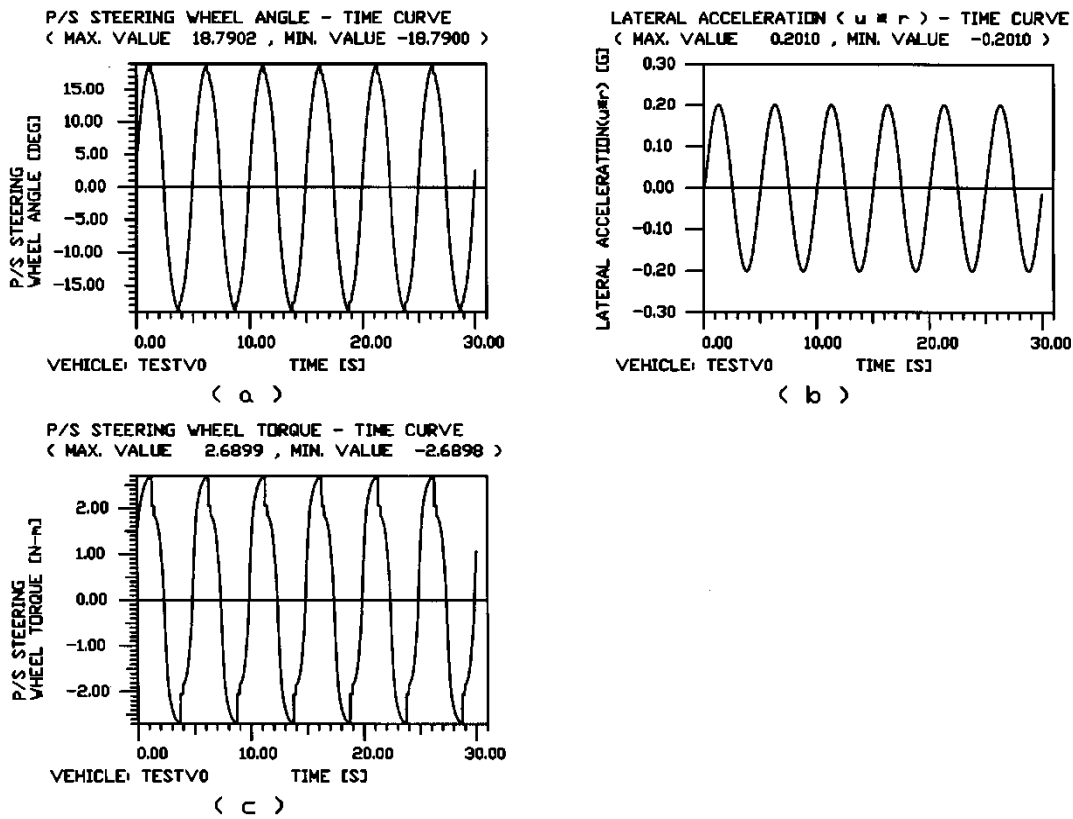


Fig. 9: Time histories of  $\delta_{SW}$ ,  $T_{SW}$ , and lateral acceleration  $a_y(u \cdot r)$

#### IV. ON-CENTER HANDLING CROSS-PLOTS AND PARAMETERS

On-center handling cross-plots (as shown in Fig. 10) are drawn from the time histories shown in Fig.

9 and the on-center handling parameters (as shown in Table 3) are obtained from the cross-plots by using the methods described by Norman (1984).

Table 3: Values of the on-center handling parameters obtained by simulation

---

Steering sensitivity at 0.1g ( g's/100deg SW ) :	1.40
Minimum steering sensitivity ( g's/100deg SW ) :	0.72
Steering sensitivity ratio:	0.52
Steering hysteresis ( deg SW):	6.95
Steering torque at 0.0g (Nm):	1.34
Steering torque gradient at 0.0g ( Nm/g ):	20.64
Steering torque at 0.1g ( Nm ):	2.34
Steering torque gradient at 0.1g ( Nm/g ):	5.54
Steering torque gradient ratio:	0.27
Lateral acceleration at 0.0Nm (g's):	-0.057
Steering torque at 0.0deg SW (Nm):	0.63
Steering torque gradient at 0.0 deg SW (Nm/deg):	0.21
Steering work sensitivity (g <sup>2</sup> /100Nm):	4.3

---

Compared with the data provided by Norman (1984) and Kunkel et al (1988), the simulation results as shown in Table 3 are reasonable.

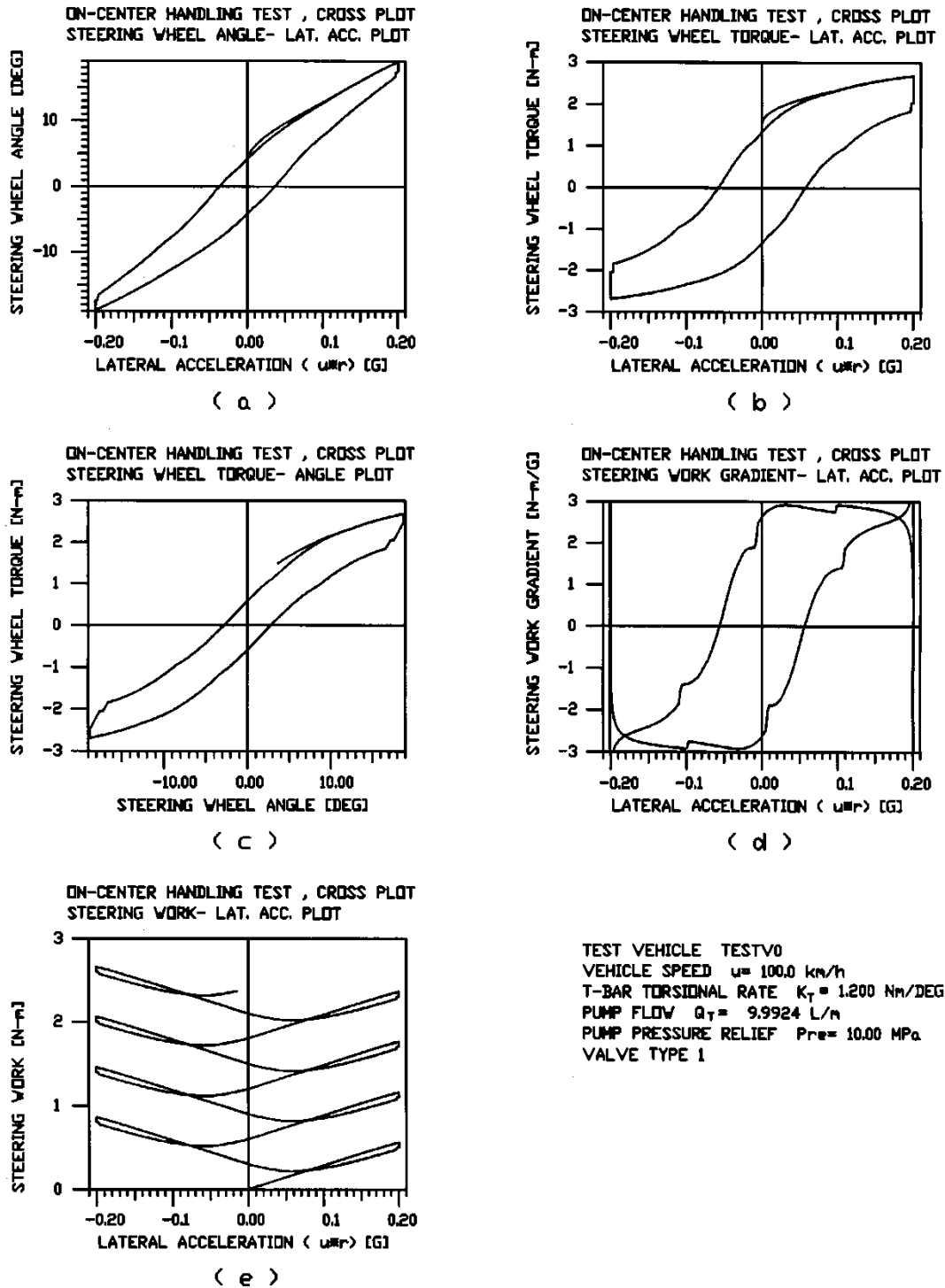


Fig. 10: On-center handling cross-plots ( $Q_T=9.992$  L/m)

The effects of changing the values of the vehicle and its steering system parameters on the on-center handling characteristics can be studied with the simulation, which helps to find the appropriate system parameters combination to make a car have good on-center handling characteristics. For example, if only  $Q_T$  (flow from the power steering pump to the steering gear) is changed from 9.992 L/m to 4.996 L/m, with all other

parameters kept unchanged, in the above simulation, the new simulation results are shown in Fig. 11 and Table 4. The steering torque gradient at 0.0g are changed from 20.64 ( Nm/g ) to 26.3 ( Nm/g ) and steering work sensitivity from 4.3( $g^2/100Nm$ ) to 3.1( $g^2/100Nm$ ), which are got improved.

Table 4: New values of the on-center handling parameters obtained by simulation \*

Steering sensitivity at 0.1g ( g's/100deg SW )	: 1.50
Minimum steering sensitivity ( g's/100deg SW )	: 0.67
Steering sensitivity ratio	: 0.44
Steering hysteresis ( deg SW)	: 8.34
Steering torque at 0.0g (Nm)	: 1.74
Steering torque gradient at 0.0g ( Nm/g )	: 26.03
Steering torque at 0.1g ( Nm )	: 2.91
Steering torque gradient at 0.1g ( Nm/g )	: 3.77
Steering torque gradient ratio	: 0.15
Lateral acceleration at 0.0Nm (g's)	: -0.055
Steering torque at 0.0deg SW (Nm)	: 0.63
Steering torque gradient at 0.0 deg SW (Nm/deg)	: 0.22
Steering work sensitivity (g <sup>2</sup> /100Nm)	: 3.1

\* Compared with the simulation in the Table 3, only the flow from the power steering pump to the steering gear  $Q_T$  is changed from 9.992 L/m to 4.996 L/m, with all other parameters kept unchanged.

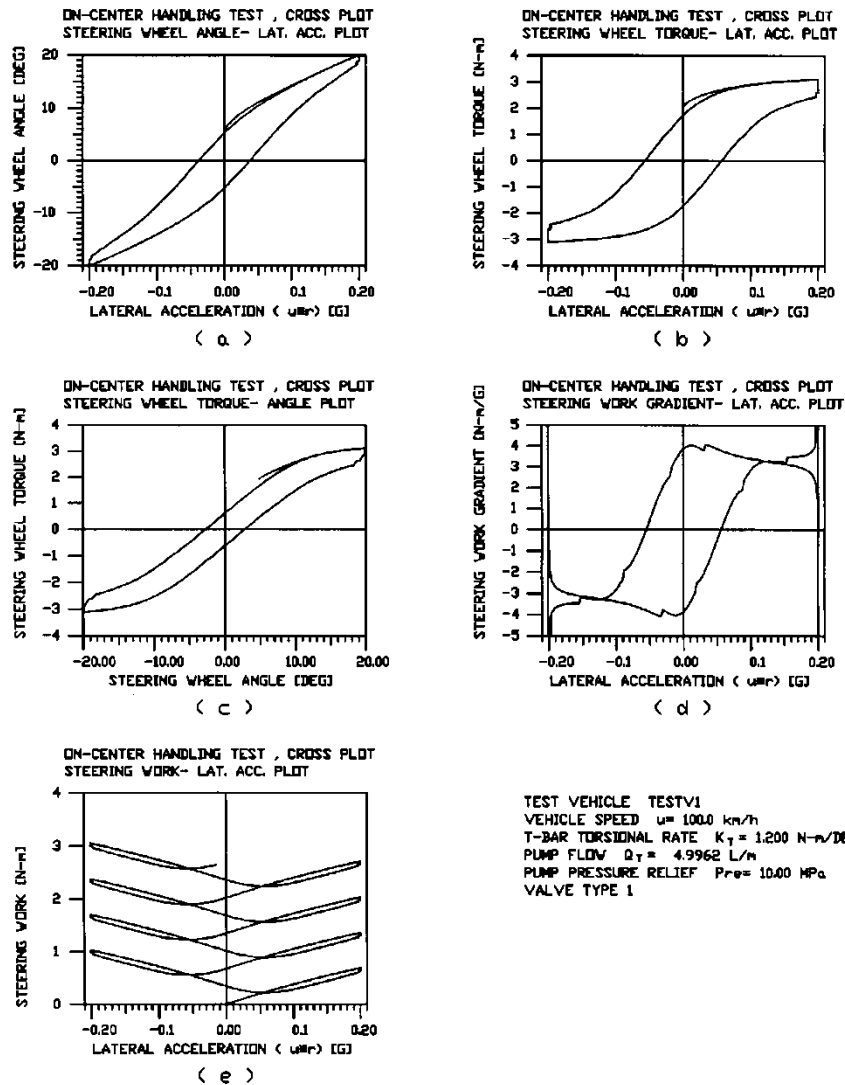


Fig. 11: On-center handling cross-plots ( $Q_T=4.996$  L/m)



## V. CONCLUSION

In the simulation of on-center handling test, a simple linear 3-dof (degrees of freedom) vehicle handling model and a comprehensive power integral steering system model are incorporated to calculate the time histories of steering wheel angle, steering wheel torque, and vehicle lateral acceleration, from which the on-center handling cross-plots and parameters are obtained. The linear 3-dof vehicle handling model can give sufficiently accurate simulation results in the lateral acceleration range (peak value is about 0.2g) of the on-center handling tests. Because the rotation angle amplitude and frequency of the steering wheel are small, the inertia forces and moments of all parts in the steering system can be neglected, which makes the steering system model much simpler. Compared with the data presented in the literatures, the simulation results obtained are reasonable. So the simulation can be useful in finding the appropriate system parameters combination to make a car have good on-center handling characteristics.

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# Isolated Traffic Signal Control using Nash Bargaining Optimization

By Hossam M. Abdelghaffar, Hao Yang & Hesham A. Rakha

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**Abstract-** This paper presents a novel isolated traffic signal control algorithm based on a game-theoretic optimization framework. The algorithm models a signalized intersection considering four phases, where each phase is modeled as a player in a game in which the players cooperate to reach a mutual agreement. The Nash bargaining solution is applied to obtain the optimal control strategy, considering a variable phasing sequence and free cycle length. The system is implemented and evaluated in the INTEGRATION microscopic traffic assignment and simulation software. The proposed algorithm is compared to an optimum fixed-time plan and an actuated control algorithm to evaluate the performance of the proposed Nash bargaining approach for different traffic demand levels. The simulation results demonstrate that the proposed Nash bargaining control algorithm outperforms the fixed-time and actuated control algorithms for the various traffic conditions. The benefits are observed in improvements in the stopped delay, queue length, travel time, average vehicle speed, system throughput, fuel consumption, and emission levels.

**Keywords:** traffic signal control, game theory, nash bargaining, integration software.

**GJRE-B Classification:** FOR Code: 090299



*Strictly as per the compliance and regulations of :*



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# Isolated Traffic Signal Control using Nash Bargaining Optimization

Hossam M. Abdelghaffar <sup>α</sup>, Hao Yang <sup>σ</sup> & Hesham A. Rakha <sup>ρ</sup>

**Abstract-** This paper presents a novel isolated traffic signal control algorithm based on a game-theoretic optimization framework. The algorithm models a signalized intersection considering four phases, where each phase is modeled as a player in a game in which the players cooperate to reach a mutual agreement. The Nash bargaining solution is applied to obtain the optimal control strategy, considering a variable phasing sequence and free cycle length. The system is implemented and evaluated in the INTEGRATION microscopic traffic assignment and simulation software. The proposed algorithm is compared to an optimum fixed-time plan and an actuated control algorithm to evaluate the performance of the proposed Nash bargaining approach for different traffic demand levels. The simulation results demonstrate that the proposed Nash bargaining control algorithm outperforms the fixed-time and actuated control algorithms for the various traffic conditions. The benefits are observed in improvements in the stopped delay, queue length, travel time, average vehicle speed, system throughput, fuel consumption, and emission levels. Specifically, the simulation results show a reduction in the average travel time ranging from 37% to 65%, a reduction in the total delay ranging from 41% to 64%, a reduction in the queue length ranging from 58% to 77% and a reduction in the emission levels ranging from 6% to 17%.

**Keywords:** traffic signal control, game theory, nash bargaining, integration software.

## I. INTRODUCTION

Traffic congestion affects traveler mobility and accessibility and produces problems and challenges for transportation agencies. Reduction in traffic congestion improves these conditions while also reducing transportation-related energy and environmental impacts. Accordingly, optimizing the utilization of the available infrastructure using advanced control techniques has become increasingly necessary to mitigate traffic congestion in a world with growing pressure on financial and physical resources.

A signalized intersection is designed (controlled) to allow traffic flow to proceed efficiently and safely by separating conflicting movements in time rather than in space. Traffic signal control methods attempt to minimize various traffic parameters (e.g., delay, queue length, and energy and emission levels),

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by optimizing traffic signal parameters, including the cycle length, phase scheme, phase split and offset. Consequently, traffic signal optimization algorithms attempt to identify the optimal values of one or more traffic signal parameters for specific traffic conditions. Most of the currently implemented traffic signal systems could be categorized as one of the following: fixed-time plan (FP), actuated (ACT), or adaptive [1].

An FP is developed off-line using historical traffic data to compute traffic signal timings; real-time traffic data is not considered. Thereafter, the order and duration of all phases remain fixed and do not adapt to fluctuations in traffic demand. As a result, FPs are known to age with time, they are suitable for relatively stable and regular traffic flows. However, because the traffic system is a dynamic system, one particular predefined traffic signal plan cannot efficiently fit all real-time traffic conditions [2].

Examples of software that compute signal timings are TRANSYT-7F, and PASSER. TRANSYT-7F is a macroscopic deterministic optimization and simulation model that considers platoons of vehicles instead of individual vehicles. The model attempts to minimize a disutility index based on delay, stops, and queue lengths [3]. This approach has been found to only be appropriate for under-saturated conditions [4]. PASSER is an arterial-based, bandwidth optimizer (i.e., it maximizes the green band to move the anticipated platoon of vehicles through the arterial signal system without stopping) that computes phase sequences, cycle lengths, and offsets for a maximum of 20 intersections in a single run [4]. PASSER works within a given cycle length and split to find offsets that maximize an arterial green band.

Actuated traffic signal control, on the other hand, responds to changes in traffic demand patterns. This type of control requires that vehicle detectors be installed at approach stop lines to the intersection. The actuated timing plan responds to traffic demand by placing a call to the controller at the presence or absence of vehicles approaching or leaving the intersection, respectively. Once a call is received, the controller decides whether to extend or terminate the green phase in response to the actuation source. Note, however, that while actuated signal control was proven to perform better than fixed-time traffic signal control in most cases, actuated traffic signal control does not offer any real-time optimization to properly adapt to traffic fluctuations.

Consequently, actuated signal control is less sensitive to the traffic demand (i.e., number of vehicles) calling for the actuation and might result in very long queues in grid-like networks [5].

Adaptive systems use detector inputs, historical trends, and predictive models to predict traffic arrivals at intersections. Using these predictions, they determine the best gradual changes in cycle length, splits, and offsets to optimize an objective function, such as minimizing the delay or the queue length, for intersections within a predetermined subarea of a network [6]. Examples in this category are the SCOOT and SCATS systems. The SCOOT system minimizes a performance index that is a function of delay and number of vehicle stops at all approaches in the network [7]. SCOOT performs effectively in under-saturated traffic conditions, and is a macroscopic model that does not capture microscopic behavior such as gap acceptance and lane changing behavior. SCATS monitors the traffic flows and headways at the stop bars [8]. Based on the volumes and headways gathered in one-minute intervals, green times (splits) are reallocated to the phases of greatest need. Other examples of adaptive systems are RHODES [9] and OPAC [10], which optimize an objective function for a specified rolling horizon (using traffic prediction models) and have pre-defined sub-areas (limited flexibility) in which the signals can be coordinated. RHODES and OPAC are based on dynamic programming that require a state transition probability model for the traffic environment, which is difficult to obtain.

One of the main disadvantages of actuated and adaptive traffic control algorithms is that their operation is constrained by maximum and minimum values for cycle lengths, splits, and offsets. In addition, some of today's most sophisticated traffic control systems use hierarchies that either partially or completely centralize the decisions, making the systems more vulnerable to failures in one of the master controllers. In such events, the entire area of influence of the master traffic signal, which may include several intersections, will be compromised by a single failure. Hierarchies also make systems more difficult to scale up, as centralized computers will need to interconnect all intersections within pre-defined subareas, creating limitations and requirements as the network is expanded [11].

Traffic flow is highly dependent on factors such as time-of-day, day-of-the-week, weather, and unpredictable events such as incidents, special events, work zones, etc. Consequently, improvements to traffic control strategies could be made if the control system is able to not only respond to the actual conditions found in the field, but also to adapt their actions to transient conditions. Cycle-free strategies could also offer a new, less restrictive perspective to accommodate changes in traffic conditions. Game theory is considered a suitable

method that has the potential to adapt to traffic fluctuations and randomness of traffic systems, and therefore alleviate traffic congestion more effectively than the more commonly used FP and ACT systems [12].

Game theory studies the interactive cooperation between intelligent rational decision makers, and has been widely used in economic, military, and communication. Game theory has also been applied to model traveler route choice behavior [13], control connected vehicle movements [14], and in route guidance [15]. Tan et al. [16], were the first to use Nash bargaining (NB) to optimize the operation of a two-phase traffic signal. The performance of their algorithm was assessed using the average speed of all vehicles in the network. Apart from this study, the literature indicates that game-theoretic traffic signal control is very limited.

In this paper, we develop the NB algorithm, which uses a cycle-free control strategy to optimize isolated signalized intersection traffic signal timings. The algorithm is then tested on a signalized intersection located in the heart of downtown Toronto's financial district, with four approaches comprised of three lanes each, considering different traffic demand levels. To evaluate the performance of the NB approach, each of the following is calculated per movement: average travel time, average stopped delay, average queue length, average vehicle speed, average vehicle throughput, average fuel consumption and average emission levels. Results are then compared with the results obtained using FP and ACT controllers, given that it is difficult to find a benchmark with available operational details due to commercial reasons.

The paper is organized as follows. Section II describes the game theory concept and NB solution, and describes how to control a signalized intersection using a game theoretic framework. Section III discusses and summarizes the simulation setup and the results for different traffic volume situations. Section IV summarizes and concludes the work.

## II. TRAFFIC SIGNAL CONTROL NASH BARGAINING SOLUTION

This section describes the NB solution for two players as shown in Section II-A, and how the approach is extended to four players to control a signalized intersection, as shown in Section II-B.

### a) NB Solution for Two Players Considering a Cooperative Game

A bargaining situation is defined as a situation in which multiple players with specific objectives cooperate and benefit by reaching a mutually agreeable outcome (agreement). In bargaining theory, there are two concepts: the bargaining process and the

bargaining outcome. The bargaining process is the procedure that bargainers follow to reach an agreement (outcome), and the bargaining outcome is the result of the bargaining process. Nash adopted an axiomatic approach that abstracts the bargaining process and considers only the bargaining outcome [17], [18]. Bargaining theory is related to cooperative games through the concept of NB. The NB solution has been applied in a number of applications, including multimedia resource management [19], allocating multi-user channels to networks [20], a wireless cooperative relaying network [21], investment, wages and employment [22], [23], and for downlink beam forming in an interference channel [24].

The bargaining problem consists of three basic elements: players, strategies, and utilities (rewards). Bargaining between two players is illustrated in the bi-matrix shown in Table I. Each player, namely P1 and P2, has a set of possible actions A1 and A2, whose outcome preferences are given by the utility functions  $u$  and  $v$ , respectively, as they take relevant actions. The utility area ( $S$ ) of the two player cooperation game is shown in Fig. 1; the vertices of the

Table 1: Two Players Matrix Game

		P <sub>2</sub>	
		A <sub>1</sub>	A <sub>2</sub>
P <sub>1</sub>	A <sub>1</sub>	$u_1, v_1$	$u_2, v_2$
	A <sub>2</sub>	$u_3, v_3$	$u_4, v_4$

area are the utilities where each player chooses their pure strategy. The disagreement or the threat point  $d = (d_1; d_2)$  corresponds to the minimum utilities that the players want to achieve. The disagreement point is a benchmark, and its selection affects the bargaining solution. Each player attempts to choose their disagreement point in order to maximize their bargaining position. The NB solution can be obtained from the following maximization problem:

$$\begin{aligned} & \max_{u,v} (u - d_1)(v - d_2), \\ & s.t. (u, v) \in S, (u, v) \geq (d_1, d_2) \end{aligned} \quad (1)$$

The NB solution ( $u^*; v^*$ ) of this optimization problem can be calculated as the point in the bargaining set that maximizes the product of the players utility gains relative to a fixed disagreement point.

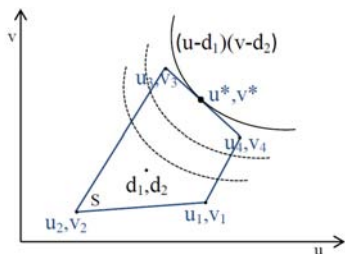


Fig. 1: Utility region

b) Traffic Signal NB Solution for Four Players

This section describes the game model and the NB solution for four players, and shows how the model is adapted and applied to control a four-phase signalized intersection. First, we use the standard NEMA phasing for a four-legged intersection to represent the intersection phases as shown in Fig. 2, with protected, leading main street left-turn phases.

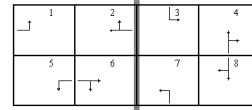


Fig. 2: Standard NEMA phasing [25]

In the game model, the four phases represent the players P1, P2, P3, and P4 of a four player cooperation game. For each player (phase), there are two possible actions: maintain (A1) or change (A2). These actions represent the state of the traffic signal. Specifically, maintain indicates that the state of the signal will not change (i.e., if it is green, it will remain green; if it is red, it will remain red.). Change means the state of the signal will change (i.e., if it is green, it will switch to yellow and then red; if it is red, it will become green.) in the simulated time interval. The combinations of phases offer four possibilities, where only one player holds the green indication and all others hold red indications.

In the simulation, the INTEGRATION traffic simulation software monitors the vehicle speeds and the vehicle flow approaching the intersection and continuously updates them for each lane connected to the signalized intersection. If the vehicle ( $v$ ) speed ( $s_v^t$ ) is less than a certain threshold speed ( $s^{Th}$ ) at time ( $t$ ), the vehicle is assigned to the queue, and the current queue length associated with the corresponding lane ( $l$ ) is updated. Once the vehicle's speed exceeds ( $s^{Th}$ ), the queue length is updated (i.e., shortened by the number of vehicles leaving the queue) and formulated mathematically

$$q_l^t = \sum_{v \in v_l^t} q_v^t \quad (2)$$

$$q_v^t = \begin{cases} 1 & \text{if } s_v^{t-1} > s^{Th} \ \& \ s_v^t \leq s^{Th} \\ -1 & \text{if } s_v^{t-1} \leq s^{Th} \ \& \ s_v^t > s^{Th} \\ 0 & \begin{cases} \text{if } s_v^{t-1} \leq s^{Th} \ \& \ s_v^t \leq s^{Th} \\ \text{if } s_v^{t-1} > s^{Th} \ \& \ s_v^t > s^{Th} \end{cases} \end{cases} \quad (3)$$

$q_l^t$  is the number of queued vehicles in lane  $l$  at time  $t$ .

The utilities (rewards) for each player (phase) in the game can be defined as the estimated sum of the queue lengths in each phase after applying a specific action. The estimated queue length after applying a specific action is calculated according to the following equation:

$$Q_P(t + \Delta t) = \sum_{l \in P} q_l^t + Q_{inl} \Delta t - Q_{outl} \Delta t \quad (4)$$



Where  $\Delta t$  is the updating time interval,  $q_i^t$  is the current queue length at time  $t$ ,  $QP(t + \Delta t)$  is the estimated queue length after  $\Delta t$  for phase  $P$ ,  $Q_{inl}$  is the arrival flow rate (veh/h/lane), and  $Q_{outl}$  is the departure flow rate (veh/h/lane).

The objective is to minimize and equalize the queue lengths across the different phases [26], [27]. We use minus queue length as the utility of each strategy. The NB solution is extended to four players with a four-dimensional utility space and disagreement points. The solution for the NB over the four phase combinations has the following formula:

$$\max_{(u_1, \dots, u_4)} \prod_{i=1}^4 (u_i - d_i) \quad (5)$$

$$s.t. (u_1, \dots, u_4) \in S, (u_1, \dots, u_4) \geq (d_1, \dots, d_4)$$

The NB solution can be calculated as the vector that maximizes the product of the player's utility gains relative to a fixed disagreement point.

### III. SIMULATION SETUP AND RESULTS

This section describes the testbed intersection used in the simulation study (Section III-A), the traffic simulator used in the simulation (Section III-B), the measures of effectiveness used to evaluate the performance of the system (Section III-C), the simulation parameters (Section III-D), and the simulation results

when applying the various control strategies (Section III-E).

#### a) Test bed Intersection

The simulation results were tested on an intersection with four approaches comprised of three lanes each located in the heart of downtown Toronto's financial district (intersection of Front and Bay streets) [28], as shown in Fig. 3.

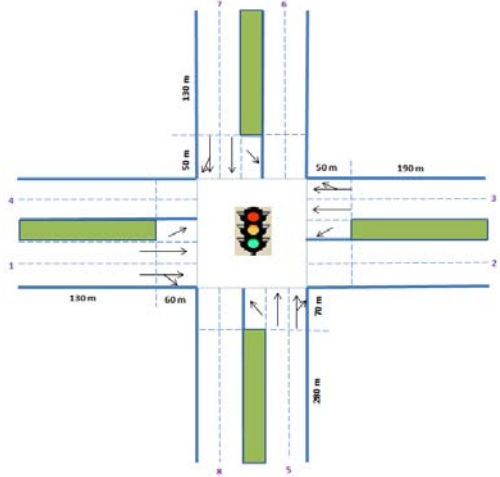


Fig. 3: Simulated Intersection in downtown Toronto.

The traffic demand origin-destination (O-D) matrix provided in Table II [29], represents the highest total demand approaching the intersection during the afternoon rush hour (PM Peak) for the year 2005.

Table 2: Origin Destination Demand Matrix

Zone #	2	4	6	8	Total
1	1223	-	134	121	1478
3	-	844	86	278	1208
5	88	71	721	-	880
7	188	100	-	806	1094
Total	1499	1015	941	1205	4660

#### b) Traffic Simulator

INTEGRATION software was used to model the intersection [30]. It is a microscopic traffic simulation model that traces individual vehicle movements every deci-second. Driver characteristics such as reaction times, acceleration and deceleration rates, desired speeds, and lane-changing behavior are examples of stochastic variables that are incorporated in INTEGRATION [31].

#### c) Measures of Effectiveness (MOEs)

The following measures of effectiveness were used to evaluate the performance of the system:

- Average Total Delay (s/veh): the sum of delay each decisecond for all vehicles for the entire simulation horizon divided by the number of vehicles.
- Average Stopped Delay (s/veh): the sum of instances where vehicle speed is less than or equal

3.6 km/h (pedestrian speed) divided by the number of vehicles.

- Average Queue Length (veh): the sum of vehicles in queue each second divided by the simulation duration.
- Average Travel Time (s): the summation of all trip times divided by the number of vehicles.
- Average Vehicle Speed (km/h): the sum of instantaneous vehicle speeds divided by the number of vehicles.
- Average Throughput (veh/h): the total number of vehicles exiting the intersection divided by the simulation duration.
- Average Fuel (L): the total volume of fuel consumed by vehicles divided by the number of vehicles.
- Average CO<sub>2</sub> (grams): the total amount of CO<sub>2</sub> produced divided by the total number of vehicles.



- Last Vehicle Arrival Time(s): the arrival time of last vehicle to its destination.

#### d) Simulation Parameters

The fixed time signal plan was optimized using the Webster method [2], with yellow time of 3s, and all red time of 2s. The optimized effective green time for the four phases shown in Fig. 2 were, 19s, 47s, 14s, 32s, respectively. The actuated control was implemented with minimum green time of 10s, maximum green time of 78s, and green extension time of 5s. The simulations were conducted using the following parameter values; speed at capacity = 60 (km=h), free flow speed = 80 (km=h), jam density = 160 (veh=km=lane), saturation flow rate = 1900 (veh=h=lane), and threshold speed  $sTh = 4:5$  (km=h).

#### e) Results and Discussion

An optimum FP and an ACT controllers were simulated to serve as benchmarks to evaluate the performance of the NB approach. Vehicles were allowed to enter the links in the first hour, and the simulation ran for an extra half hour to guarantee that all vehicles exited the network. Three scenarios were simulated: one for

the original O-D demand shown in Table II, the second for a lower demand (L-D), i.e., (-25%) of the original demand, and the third for higher demand (H-D), i.e., (+25%) of the original demand.

- 1) *Original Demand (O-D)*: The simulation results shown below were obtained using three signal control systems: FP, ACT, and NB. The MOEs are shown in Table III to quantify the effect of each control system on the performance of the signalized intersection. Five cases were conducted at different threat points (d), and at different updating intervals for NB ( $t$ ) in order to study their effect on the performance of the NB algorithm. First, the performance of the intersection using the three control systems (FP, AC, NB) was investigated, at the following parameters values:

$$\text{Case 1} \Rightarrow d = (-17, -34, -19, -38), \Delta t = 15s$$

The threat point was chosen based on the number of cars that left turn pocket lanes could accommodate to prevent spill

Table 3: Overall Intersection Performance Measure For Different Control Systems

MOE	System		Nash Bargaining				
	Fixed Plan	Actuated	Case 1	Case 2	Case 3	Case 4	Case 5
Average Total Delay (s/veh)	74.268	76.270	32.176	29.390	26.906	43.312	48.148
Average Stopped Delay (s/veh)	46.878	48.77	15.837	13.619	9.553	11.158	25.010
Average Queue Length (veh)	8.294	8.559	2.781	2.484	1.891	2.955	4.623
Average Travel time (s)	116.141	137.566	53.366	50.577	48.080	74.280	69.879
Average Vehicle Speed (km/h)	21.455	20.617	38.965	38.302	39.954	31.514	31.501
Average Throughput (veh/h)	529.545	529.545	554.762	563.710	563.710	554.762	554.762
Average Fuel (L)	0.1197	0.1212	0.1028	0.1017	0.1037	0.1167	0.1097
Average CO2 (grams)	255.80	258.89	213.708	211.290	213.324	240.083	231.400
Last Vehicle Arrival time (s)	3852.3	3906.1	3701.1	3664.3	3672.3	3676.4	3693.2

back into the through lane, where this number is duplicated for the right and the through movements.

The simulation results shown in Table III show that the NB approach outperforms the optimum FP and ACT controller. Since the traffic flow is high on all approaches, no considerable difference is reported between the FP and the ACT controllers. The NB approach exhibits significant savings in the average total delay, average stopped delay, average queue length, and average travel time. The NB shows an increase in the average vehicle speed and in the throughput.

Subsequently, the performance of the intersection using the proposed NB approach was investigated using different threat points values and at the same updating interval, using the following parameters values

$$\text{Case 2} \Rightarrow d = (-17, -55, -19, -51), \Delta t = 15s$$

In this case, the threat point was chosen based on the number of cars that each phase can accommodate based on the lane lengths, shown in Fig. 3, where the right turn and through lanes can

accommodate more cars than the left turn lanes. The results shown in Table III show that MOEs in case 2 outperform the results in case 1.

Finally, three more simulations were conducted using the proposed NB algorithm to investigate the effect of the choice of the updating time interval on the algorithm performance using the same threat point values.

$$\text{Case 3} \Rightarrow d = (-17, -55, -19, -51), \Delta t = 10s$$

$$\text{Case 4} \Rightarrow d = (-17, -55, -19, -51), \Delta t = 5s$$

$$\text{Case 5} \Rightarrow d = (-17, -55, -19, -51), \Delta t = 20s$$

The results shown in Table III show that case 3 outperforms the results of the other cases, as well as the FP approach and the ACT approach.

Fig. 4 shows the average queue length and the standard deviation across all movements for each control system, (FP, ACT, and NB). The NB algorithm shows significant reduction in the queue length.

Fig. 5 shows the average values and the standard deviations of the MOEs across all movements over the entire simulation time for each control system,

(FP, ACT, and NB). The NB algorithm outperforms both FP and ACT for all movements with significant reduction in both the average

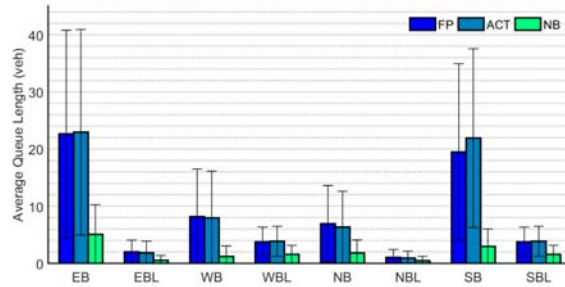


Fig. 4: Average queue length

values and the standard deviations for the total delay, stopped delay, arrival time, fuel consumption, and CO2 emission. In addition the NB algorithm shows an increase in the average vehicle speed.

The simulation results showed that, the NB control approach exhibited major improvements in both the average values and the standard deviations of all MOEs for different movements, which indicates that the system efficiency is improved.

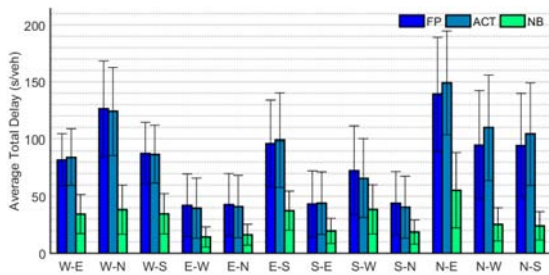
2) *Lower And Higher Demand:* To better evaluate the performance of the NB approach, two other simulations were conducted, one at lower demand (L-D), and the other at higher demand (H-D).

Table IV shows the results of using the three control approaches at the O-D, L-D, and H-D levels using the following NB algorithm parameters

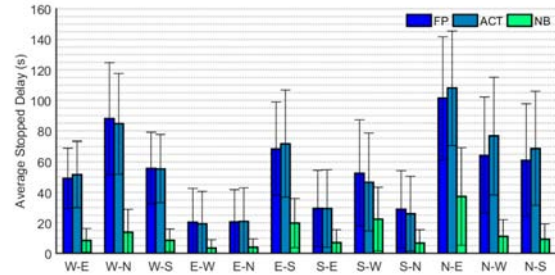
$$d = (-17, -55, -19, -51), \Delta t = 10s$$

In addition, Table IV shows the percent improvement in MOEs using the proposed NB algorithm over using either the FP or the ACT approach. The analysis of the results in Table IV leads to the following findings: the proposed NB algorithm outperforms the FP and ACT approaches in terms of average stopped delay, average queue length, average travel time, average vehicle speed, average throughput, average fuel consumed, average CO2 emitted, and time in which the last vehicle clears the network for different demand levels.

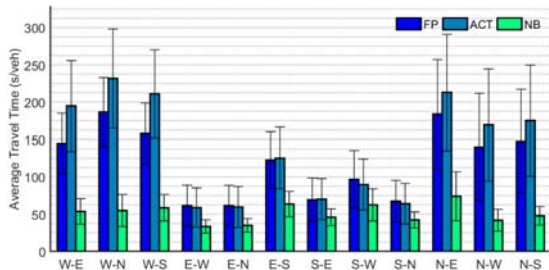
To further investigate the achieved improvements using the NB approach, simulations were conducted at different flow ratios (Y). The flow ratio can be formulated mathematically



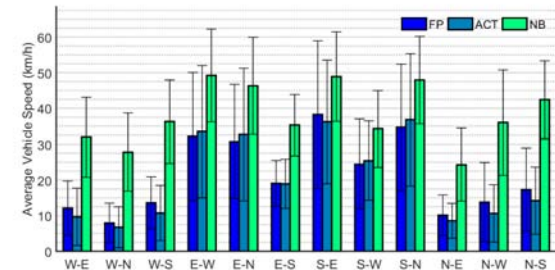
(a) Average total delay.



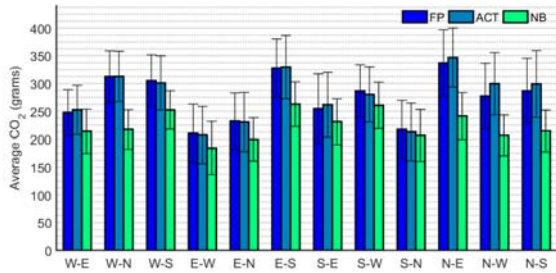
(b) Average stopped delay.



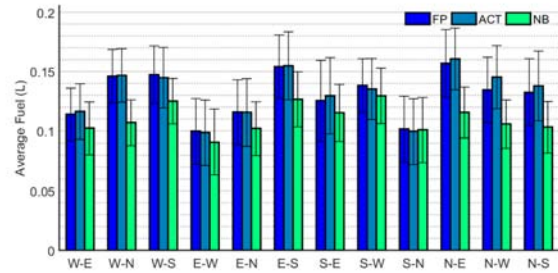
(c) Average travel time.



(d) Average vehicle speed.



(e) Average CO<sub>2</sub>.



(f) Average fuel.

Fig. 5: Measure of effectiveness

Table 5: Intersection Performance Measure For Different Control Systems At Different Demand Profiles

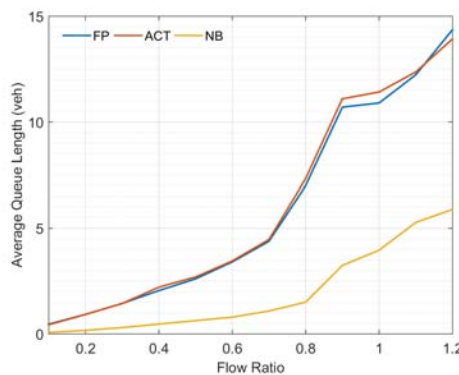
Demand	System	L-D			O-D			H-D		
		FP	ACT	NB	FP	ACT	NB	FP	ACT	NB
Total Delay (s/veh)		41.473	42.913	17.854	74.268	76.270	26.906	101.783	102.938	59.994
Improvement %		56.9503	58.3949		63.7717	64.7227		41.0570	41.7183	
Stopped Delay (s/veh)		27.157	28.222	6.357	46.878	48.77	9.553	62.730	63.679	17.970
Improvement %		76.5917	77.4750		79.6216	80.4121		71.3534	71.803	
Queue Length (veh)		3.5340	3.7087	0.8827	8.2944	8.5593	1.8907	11.4293	11.4806	4.7811
Improvement %		75.0226	76.1992		77.2051	77.9106		58.1680	58.3550	
Travel time (s)		62.602	64.035	38.961	116.141	137.566	48.080	463.612	462.311	228.149
Improvement %		37.7640	39.1567		58.6020	65.0495		50.7888	50.6503	
Vehicle Speed (km/h)		35.759	34.987	47.442	21.455	20.617	39.954	9.600	9.435	21.435
Improvement %		32.6715	35.5989		86.223	93.7915		123.2812	127.186	
Throughput (veh/h)		415.95	415.95	422.66	529.54	529.54	563.71	526.44	532.86	598.56
Improvement %		1.6129	1.6129		6.4516	6.4516		13.6986	12.3287	
Fuel (L)		0.100	0.1017	0.0974	0.1197	0.1212	0.1037	0.1328	0.1337	0.1209
Improvement %		2.6000	4.2281		13.3668	14.4389		8.9608	9.5737	
CO <sub>2</sub> (grams)		211.225	214.675	198.15	255.80	258.89	213.32	286.741	288.878	254.40
Improvement %		6.1858	7.6935		16.6052	17.6005		11.2764	11.9327	
Last Vehicle Arrival (s)		3705.2	3706.0	3652.2	3852.3	3906.1	3672.3	4884.8	4876.4	4284.2
Improvement %		1.4304	1.4517		4.6725	5.9855		12.2953	12.1442	

as

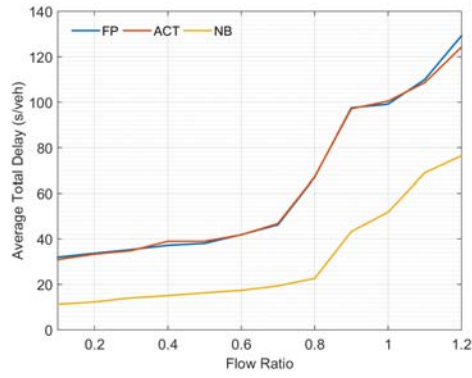
$$y_i = \frac{v_i}{s_i}, \quad Y = \sum y_{c,j} \quad (6)$$

where,  $y_i$  is the approach flow ratio for lane group  $i$ ,  $v_i$  is the traffic volume,  $s_i$  is the saturation flow rate,  $y_{c,j}$  is the critical flow ratio for all lane groups that discharge during phase  $j$ , and  $Y$  is the sum of all critical flow ratios for all phases.

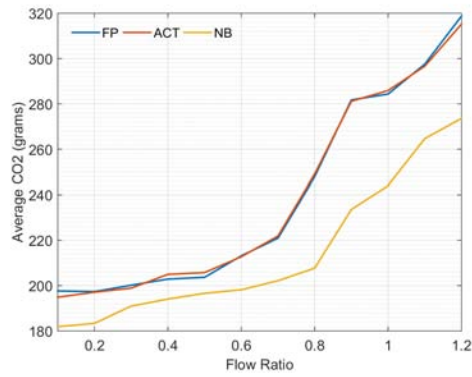
Fig. 6 shows the average queue length, the average total delay, and the average CO<sub>2</sub> at different flow ratios;  $Y$  ratios vary from 0:1 to 1:2. These results show that significant improvements are achieved using the NB approach at different traffic volumes.



(a) Average queue length.



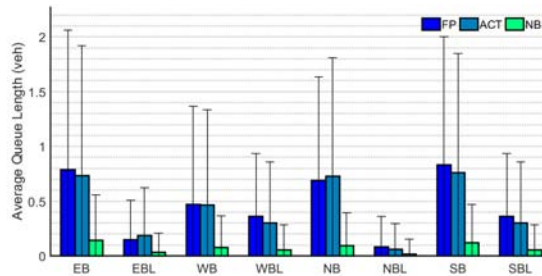
(b) Average total delay.



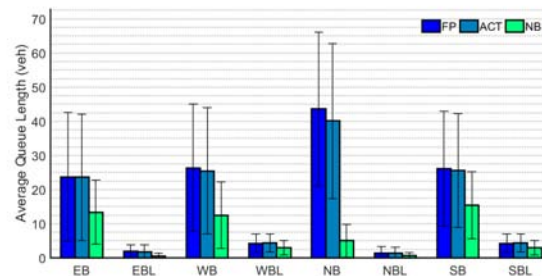
(c) Average CO<sub>2</sub>.

Fig. 6: Measure of effectiveness vs. flow ratio

Fig. 7 shows the average queue length at two different flow ratios (Y) (i.e., 0:1 and 1:2). Considerable reductions in the queue lengths were found for all movements.



(a) Average queue length at 0.1 flow ratio.



(b) Average queue length at 1.2 flow ratio.

Fig. 7: Average queue length vs. flow ratio.



In summary, the simulation results showed that the NB control approach exhibited major improvements in the MOEs for all movements when compared to FP and ACT algorithms, which improves the system efficiency.

#### IV. SUMMARY & CONCLUSIONS

The paper developed a Nash bargaining (NB) isolated traffic signal controller. The INTEGRATION microscopic traffic assignment and simulation software was used to evaluate the performance of the algorithm relative to an optimum fixedtime plan and an actuated controller on a major intersection in downtown Toronto using observed traffic data. Five NB algorithm cases were simulated considering different update time intervals and different threat point values to study the effect of these parameters on the algorithm's performance. The simulation results using the NB approach show that, using relatively short cycle lengths, it is possible to minimize delay and maximize traffic flow efficiency.

To evaluate the benefits of using the proposed approach, three scenarios were simulated using the three control approaches for different traffic demand levels.

The results show significant reductions in the average total delay ranging from 41% to 64%, a reduction in the average queue length ranging from 58% to 77%, a reduction in the emission levels ranging from 6% to 17%, a reduction in the average travel time ranging from 37% to 65%, and a reduction in the network clearance time ranging from 1% to 12%. To further investigate the achieved improvements using the NB approach, simulations were conducted at different flow ratios.

The simulation results demonstrate a significant potential for the NB approach over FP and ACT. Moreover, the results show that major improvements are achievable using the NB algorithm regardless of the traffic demand level. Ongoing research entails extending the work to test the NB algorithm on an arterial facility.

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# Investigations on the Potential of Miller Cycle for Performance Improvement of Gas Engine

By Haijun Mo, Yongquan Huang, Xiaojian Mao & Bin Zhuo

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**Abstract-** To further improve thermal efficiency, Miller Cycle was applied to a turbo-charged 338 kW gas engine. Different methods of Miller Cycle were analyzed, including three Early Intake-Valve Closing (EIVC) methods and three Late Intake-Valve Closing (LIVC) methods. After the relatively suitable methods were chosen, the combination of the Miller Cycle and higher compression ratio was extensively investigated. The experimental results demonstrated that the combination of intake valves closing 40°CA earlier (EIVC40) and the compression ratio increasing to 13, the maximum thermal efficiency reached 47% and it is about 5~7% higher than the original cycle.

**Keywords:** miller cycle, compression ratio, thermal efficiency, performance.

**GJRE-B Classification:** FOR Code: 090203



INVESTIGATIONSONTHEPOTENTIALOFMILLERCYCLEFORPERFORMANCEIMPROVEMENTOFGASENGINE

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# Investigations on the Potential of Miller Cycle for Performance Improvement of Gas Engine

Haijun Mo <sup>α</sup>, Yongquan Huang <sup>ο</sup>, Xiaojian Mao <sup>ρ</sup> & Bin Zhuo <sup>ω</sup>

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## NOMENCLATURE

CA : crank angle  
EIVC : early intake-valve closing  
LIVC : late intake-valve closing  
BDC : bottom dead center  
ABDC : after bottom dead center

## I. INTRODUCTION

Natural gas is a relatively clean alternative energy, but the higher ignition temperature, the slower flame propagation speed and the smaller coefficient of molecular after the combustion all result in lower thermal efficiency. One effective way to improve the thermal efficiency of the engine is to increase the compression ratio. But for natural gas engines, the combustion temperature will increase when the compression ratio is higher, which leads to the increase of knocking tendency, reducing the reliability and service life of the engine. To avoid knocking, the general measure is to delay the ignition timing that will cancel out the improving of thermal efficiency caused by the increase of the compression ratio [1, 2].

Changing the intake valve closing time so the mixture in cylinder goes through an expansion process before the compression stroke, Miller cycle can decrease the maximum combustion temperature to some extent, combined with a higher compression ratio; it can improve the thermal efficiency. In this paper, the

engine performance of applying the Miller cycle on a nature gas engine was studied by simulation, and optimized by different levels of compression ratio. Simulation results indicated that the combination of intake valves closing 40°CA earlier(EIVC40) and the compression ratio increasing to 13 was the most potential method to further improve thermal efficiency, and experimental results proved that the method made engine fuel consumption rate got worse at high engine speeds but improved at media and low speeds, the engine knocking tendency increased at the same time.

## II. CONCEPT OF MILLER CYCLE

In comparison with the standard cycles, miller cycle is shown in Figure 1 (a). Standard cycle of a gas engines is 1-5-2-3-4-6-7-1, 1-5 is the intake stroke, after the piston moves down to the bottom dead center (point 5) the intake valves are closed; 5-2 is the compression stroke; 2-3-4 is the expansion stroke; 4-6-7 is the exhaust stroke.

EIVC Miller cycle is 1-1a-5a-2a-3a-4a-6-7-1, 1-1a is the intake stroke, the intake valves are closed at point 1a, the piston continues to move down to the bottom dead center(BDC) which is denoted by point 5a, from 1a to 5a the in-cylinder mixture expands, which makes the in-cylinder temperature drops, so when the piston reach BDC, the temperature of the charge is lower in the Miller cycle compared to the standard cycle; the compression stroke is 5a-2a, the temperature of the charge at the point of 2a is also lower, so does the pressure; the expansion stroke is 2a-3a-4a, burst pressure and maximum combustion temperature are relatively low in miller cycle; the exhaust stroke is 4a-6-7.

Another form of Miller cycle is late intake-valve closing (LIVC), as Figure 1 (b) shows, the intake valves which should be closed at point 5 are postponed to point 1, LIVC makes the expansion ratio greater than the compression ratio, and extract heat from fuel as much as possible, which will improve the thermal efficiency.

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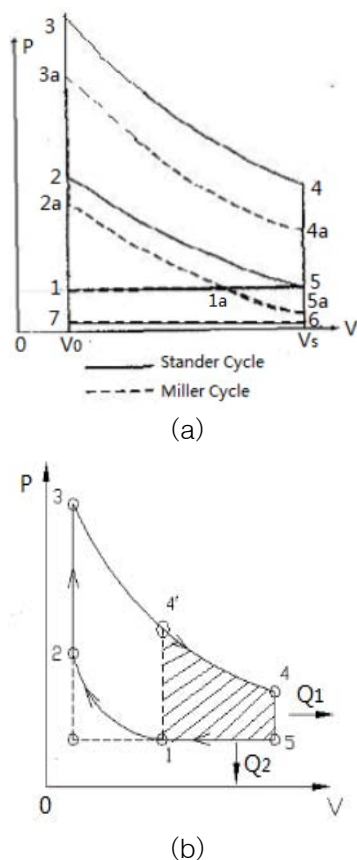


Figure 1: Theoretical Indicator Card of Miller Cycle

### III. CALCULATION OF MILLER CYCLE

From the thermodynamic point of view, Miller cycle reduces the combustion temperature, which helps to decrease knock tendency and make it possible to raise the compression ratio. In addition, Miller cycle changes the intake quantity which also has impact on the combustion process. In order to optimize the performance, one-dimensional and multi-dimensional numerical modes are set up to study the in-cylinder gas flow and heat release in a gas engine, together with experimental results. The parameters of the gas engine are shown in Table 1.

Table 1: The Main Technical Parameters of the Engine

Number of Cylinders	6
Bore/ mm	129
stroke/ mm	165
displacement/ L	12.939
Compression ratio	11 : 1
Rated power/ kW	338
Rated speed/ r/min	1900

#### a) One-dimensional Numerical Simulation of Miller Cycle

Generally speaking, in order to optimize the intake and exhaust process, the intake valves are

usually closed after bottom dead center (ABDC), EIVC or LIVC of Miller cycle discussed here is based on the intake valve close timing of original cycle which is 22°CA ABDC, not the top dead center. Six kinds of Miller cycle are proposed on the first ground, including three EIVC and three LIVC, the valve lifting curves are shown in Figure 2.

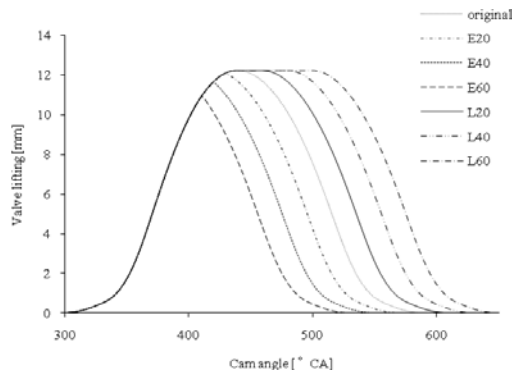


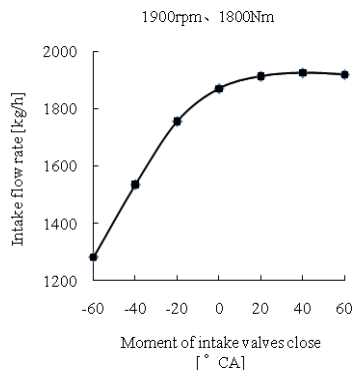
Figure 2: Six Kinds of Miller Cycle

EIVC20, intake valve close timing is at 2°CA ABDC; EIVC40, intake valve close timing is at 18°CA ABDC; EIVC60, intake valve close timing is at 38°CA ABDC; LIVC20, intake valve close timing is at 42°CA ABDC; LIVC40, intake valve close timing is at 62°CA ABDC; LIVC60, intake valve close timing is at 82°CA ABDC.

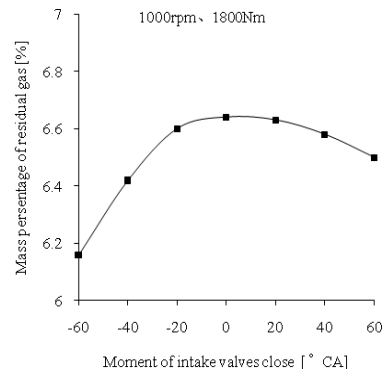
The one-dimensional model was built with the software of GT-POWER, and the heat release rate model was Weber function, the heat transfer model was Woschni 1978.

#### i. Calculation Results

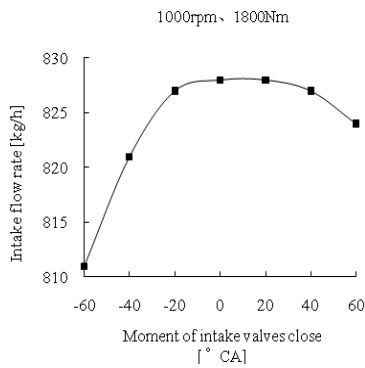
Changes of the amount of intake charge are shown in figure 3, "-60" on the abscissa indicates E60, "60" indicate L60. Keeping the opening of turbocharger bypass constant, miller cycles change the amount of intake charge. For 1900r/min, due to the longer time for intake, the later the valves close, the more charge the engine gets. Compared to the original cycle, the intake of E20, E40 and E60 decrease by 6.1%, 18% and 31.5% respectively, but intake charge doesn't change a lot from L20 to L60. For 1000r/min, EIVC's influence is not as much as 1900r/min. So in the six Miller cycles, EIVC has more influence than LIVC on the intake amount, and EIVC has more influences at the high speed working condition than the low speed working condition.



( a )



( b )

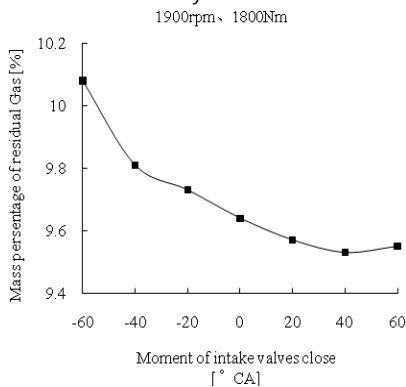


( b )

Figure 3: Change of Intake Mass Flow

ii. Change of Residual Gas

Figure 4 shows the change of residual gas of miller cycles. For high speed condition, the later the intake valves close, the less the amount of the residual gas, due to the longer time for scavenging. For low speed condition, the residual gas decreases when the intake valves close too early or too late.



( a )

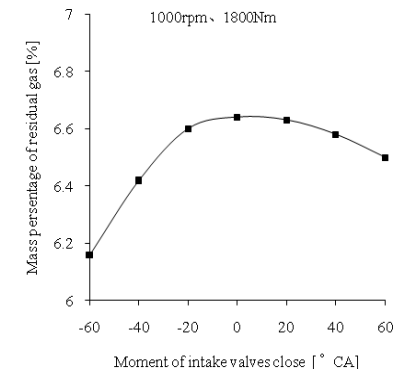


Figure 4: Change of Residual Gas

Generally speaking, the cam profile of the exhaust valve has a greater effect to the residual gas than the intake valve, Figure 5 shows the change of the residual gas according to the exhaust phase, it can be seen that, when the exhaust phase is postponed 10 ~ 20°CA, the mass fraction of residual gas reaches the smallest value. Theoretically, minimizing the residual gas is an effective measure to broaden the knock limit.

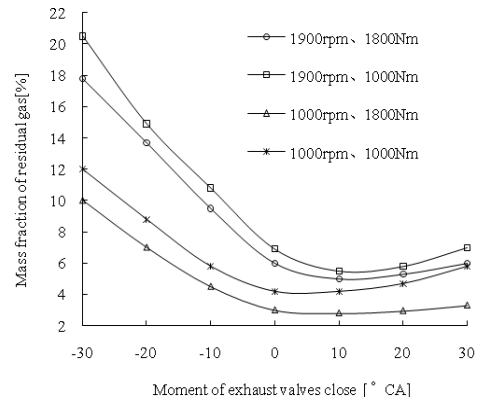
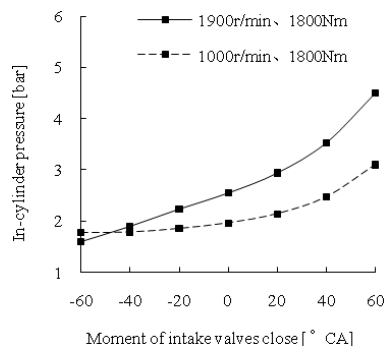


Figure 5: Change of Residual Gas with Different Exhaust Valve Close Timing

iii. Change of in-cylinder pressure and temperature when the intake valves close

The in-cylinder pressure and temperature at the time of intake valves closing both increase while the intake valves close later, as Figure 6 shows.



( a )

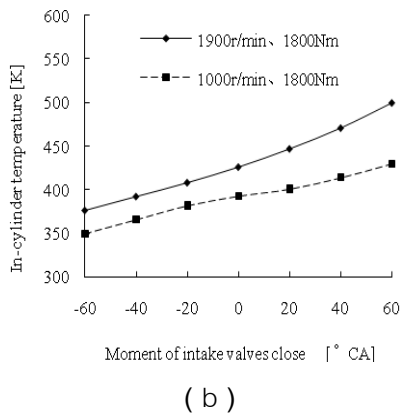


Figure 6: change of in-cylinder pressure and temperature when the intake valves close

#### iv. Change of Intake Temperature

In the case of LIVC, some of the intake charge is pushed reversely into the induct, and the compression work converted into internal energy of the fresh charge in the intake ports, which makes the intake temperature of next cycle increases, as shown in Figure 7. On the contrary, intake temperature drops obviously for EIVC because of the expansion before compression. The purpose of this paper is to reduce the compression temperature by Miller cycle, Figure 7 shows that LVIC doesn't hit the mark, so in the subsequent analysis only EVIC is taken into account.

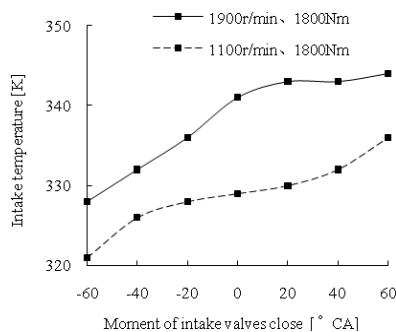


Figure 7: Changes of Intake Temperature

Through the above one-dimensional simulations, we can see that EVIC changes the intake process and decreases the in-cylinder pressure and temperature when the intake valves close, which help to reduce the maximum combustion temperature and detonation tendency, so higher compression ratio is possibly to be employed to improve the thermal efficiency. On the other hand, EVIC changes the state of air-fuel mixture, that will also changes the combustion efficiency, especially when the temperature of the mixture drops, the combustion speed will decrease, and the thermal efficiency will decrease also, so it is necessary to do further analysis for in-cylinder processes by multidimensional numerical simulation.

#### b) Multidimensional numerical simulation of in-cycle cylinder flow and combustion of EVIC

Large eddy simulation (LES) and G equation flamelet model are employed to investigate the in-cycle cylinder flow and combustion of different EVICs.

##### i. Large Eddy Simulations

When LES is used, the flow variables are decomposed into two parts, the large-scale motions that are supported by the mesh size and the small, sub-grid scale (SGS) motions that are less than the grid size. Spatial filtering is applied to both the variables and the governing equations, leading to governing equations for the resolved large-scale motions. The governing equations can be written as the following<sup>[3,4]</sup>:

$$\begin{aligned} \frac{\partial \bar{p}}{\partial t} + \frac{\partial \bar{\rho} \bar{u}_i}{\partial x_i} &= 0 \\ \frac{\partial \bar{\rho} \bar{u}_i}{\partial x_i} + \frac{\partial \bar{\rho} \bar{u}_i \bar{u}_j}{\partial x_j} &= -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial \bar{\tau}_{ij}}{\partial x_j} + \frac{\partial}{\partial x_j} (\bar{\rho} \bar{u}_i \bar{u}_j - \bar{\rho} u_i u_j) \\ \frac{\partial \bar{\rho} \bar{h}}{\partial t} + \frac{\partial \bar{\rho} \bar{h} \bar{u}_j}{\partial x_j} &= \frac{\partial \bar{p}}{\partial t} + \frac{\partial}{\partial x_j} \left( \bar{\rho} D \frac{\partial \bar{h}}{\partial x_j} \right) + \frac{\partial}{\partial x_j} (\bar{\rho} \bar{h} \bar{u}_j - \bar{\rho} h u_j) \end{aligned} \quad (1)$$

Where  $\rho$  is the density of the mixture;  $u_i$  is the velocity component in the  $x_i$  direction (1, 2, 3);  $p$  is the pressure;  $\tau_{ij}$  is the viscous stress tensor;  $D$  is the thermal diffusion coefficient; and  $h$  is the enthalpy. The overbars denote spatially-filtered quantities, whereas over-tildes denote the density-weighted spatially-filtered quantities. For example,

$$\begin{aligned} \bar{p}(x_i, t; \Delta) &= \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F(x_i - x'_i; \Delta) \rho(x'_i, t) \\ \tilde{h}(x_i, t; \Delta) &= \frac{1}{\bar{\rho}} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F(x_i - x'_i; \Delta) \rho(x'_i, t) h(x'_i, t) d^3 \zeta \end{aligned} \quad (2)$$

Where  $F$  is a filter function and  $\Delta$  is the filter width (here taken as the cell size). The last term in Eq.(2) is the SGS stress whereas the last term in Eq.(3) is the turbulent transport flux that accounts for the effect of the un-resolved sub-grid turbulence. The SGS stresses are modeled here using the scale-similarity model<sup>[5,6]</sup>, whereas the SGS scalar transport fluxes are modeled by Smagorinski model.

An equation of state is used to couple the pressure, temperature and density in the cylinder. The calorific equation of state is used to compute the temperature of the fluid from the enthalpy. In the present engine test, the in-cylinder flow speed is less than 120 m/s and the Mach number is lower than 0.3. For simplicity, in Eq. (3) the 'low Mach number approximation' has been used. With this approximation, the pressure is split into two parts, a hydrodynamic pressure and a thermodynamic pressure. The former is responsible for the pressure gradient that drives the flow, in Eq. (2). The latter depends on time (or the crank

angle) only. It is used in the equation of state to couple with the density and temperature.

ii. Ignition Model

To spark ignition engines, the current numerical grid scale is too large to capture the small structure of the initial phase of the fire kernel, so fire kernel growth in this paper is described by the discrete particle ignition kernel model(DPIK)<sup>[7]</sup>.

$$\frac{dr_k}{dt} = \frac{\rho_u}{\rho_k} (S_T + S_{plasma}) + \frac{1}{3} r_k \left( \frac{1}{T_k} \frac{dT_k}{dt} \right) \tag{3}$$

where  $r_k$  is the radius of the fire kernel;  $\rho_u$  is the density of the burned fire kernel;  $S_{plasma}$  is the Plasma growth rate;  $T_k$  is the temperature inside the fire kernel  $S_{plasma}$  is calculated by:

$$S_{plasma} = \frac{Q_{electr}}{4\pi r_k^2 \left[ \rho_u (U_k - H_u) + p \frac{\rho_u}{\rho_k} \right]} \tag{4}$$

Where  $Q_{electr}$  is ignition energy;  $U_k$  is the internal energy of the kernel;  $H_u$  is the enthalpy of the unburned charge;  $P$  is the in-cylinder pressure.

When the kernel is larger than several times the Integral length scale  $L_I$ , i.e.  $r_{k2} \geq C_k L_I$  (usually  $C_k = 2.5$ ), the combustion calculation switches to G equation flamelet model.

iii. G-equation Flamelet Turbulent Flame Propagation Model

G-equation combustion model based on flamelet theory of premixed combustion, in which turbulent flames are considered a series of laminar flames, and a G-field whose level  $G = G_0$  represents the flame surface, is introduced to simulate the propagation affront of premixed turbulent flame. The G - equation and the Navier-Stokes equations integrate into the description of turbulent premixed combustion flame front propagation, which can be written after being filtered[8]:

$$\frac{\partial \bar{G}}{\partial t} + \mathbf{u} \cdot \nabla \bar{G} = S_T^0 |\nabla \bar{G}| - \overline{D\kappa} |\nabla \bar{G}| \tag{5}$$

where  $\mathbf{u}$  is the flow velocity;  $S_L^0$  is the turbulent flame speed, which has to be modeled;  $D$  is the diffusivity;  $\kappa$  is the flame stretch ratio.

Turbulent flame speed is modeled by:

$$\frac{S_T^0 - S_L^0}{u'} = - \frac{a_4 b_3^2}{2b_1} Dal^* + \sqrt{\left( \frac{a_4 b_3^2}{2b_1} Dal^* \right)^2 + a_4 b_3^2 Dal^*} \tag{6}$$

Where  $a_4 = 0.78$ ,  $b_1 = 2.0$ ,  $b_3 = 0.1$ ,  $S_L^0$  is the laminar flame speed, Da is the Damköhler number,  $l^*$  is the process variable which indicates the relationship between the degree of development of turbulent flame and time, it can be written:

$$l^* = \left[ 1 - \exp\left(-2.0 \frac{t}{t_i}\right) \right]^{\frac{1}{2}} \tag{7}$$

Where t is the initial moment and tt is the time being considered.

The Simulation is performed on the software of KIVA. An engine mesh of medium grid density was built with the same geometry as the real engine, as figure 8 shows. The calculation point is 1900r/min-1800Nm, the excess air ratio is 1.5, a spark plug located at the center of the combustion chamber, ignition timing is 20°CA before top dead center.

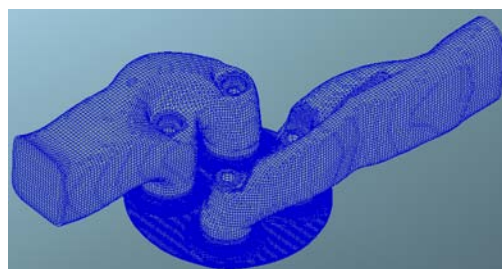
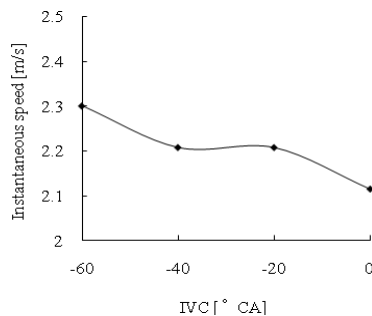


Figure 8: The gid of Model

c) Calculation Results

Figure 9 shows the change of turbulence parameters at the time of ignition around the spark plug. When the intake valve closed early, the instantaneous speed increases, which is in favor of the initial flame propagation; the integral length scale increases slightly, it means that EIVC makes the flame be more inclined to propagate at a laminar speed at the first moment; on the other hand, the fluctuation velocity and the turbulent kinetic energy decrease, Which go against the rapid spread of flame.



( a )

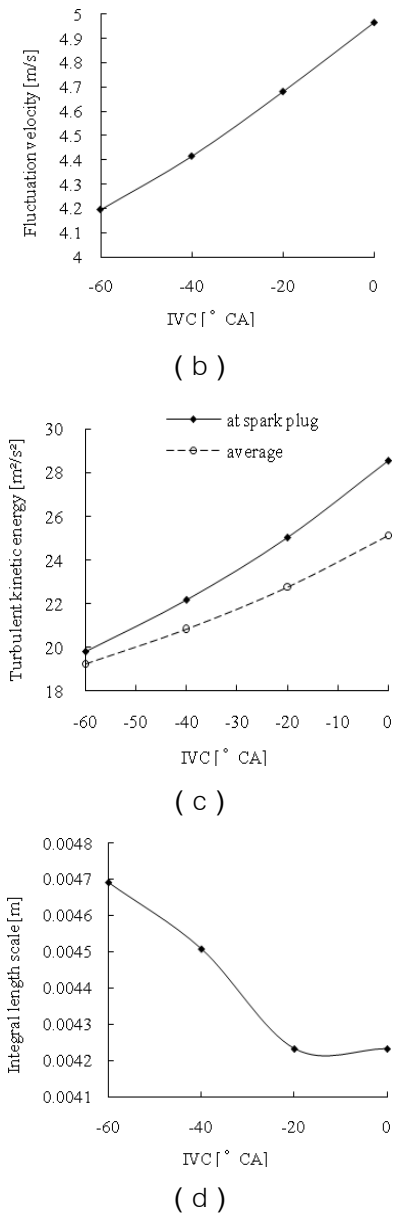


Figure 9: Comparison of Turbulence Parameters at Spark Ignition at 1900r/min, 1800Nm

Figure 10 shows the heat release, in-cylinder pressure and temperature during combustion. With the intake valves closing early, the heat release lags behind and becomes slow, so the burst pressure and the maximum temperature decrease. E20 doesn't make much difference and the in-cylinder pressure decreases too much for E60.

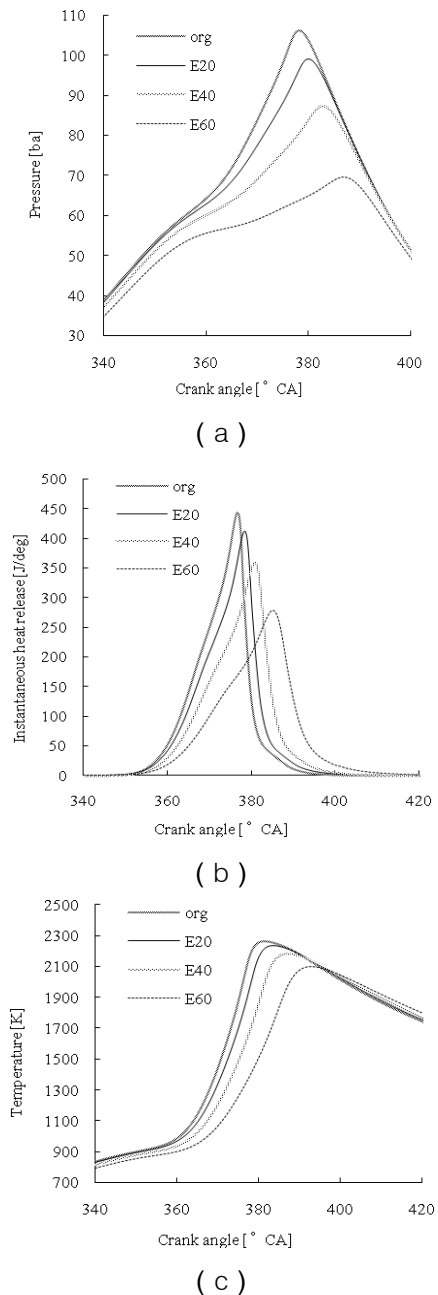


Figure 10: Burning and Heat Release at 1000r/min, 1800Nm

According to the above simulation, E40 has a lower combustion temperature and a relatively rapid combustion process compared with the original cycle, so it is chosen as a scheme to improve the gas engine's performance. Miller cycle decreases the combustion temperature, so the geometry compression ratio can be improved to optimize the engine's performances. And the next step is to optimize the compression ratio.

d) Optimization of compression ratio

The original compression ratio is 11, and the chamber profile is shown in Figure 11. Modify the main



structural parameters D and H to increase the geometric compression ratio to 12 and 13, as shown in table 2. Table 3 compares the calculated main turbulence parameters with different compression ratios at the ignition time under the condition of 1900r/min-1800N, it shows that the locate turbulence parameters don't change a lot when the compress ratio changes.

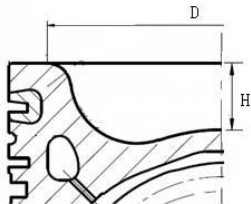


Figure 11: Sketch of Piston

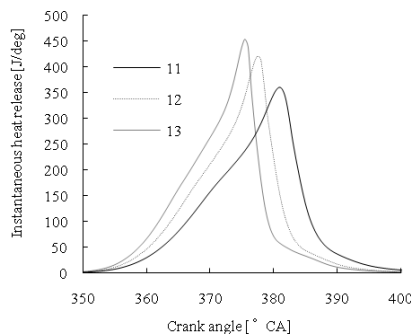
Table 2: Main Parameters of Piston with Different Compression Ratio

压缩比	D ( m )	H ( m )
11	0.118	0.024
12	0.114	0.023
13	0.109	0.022

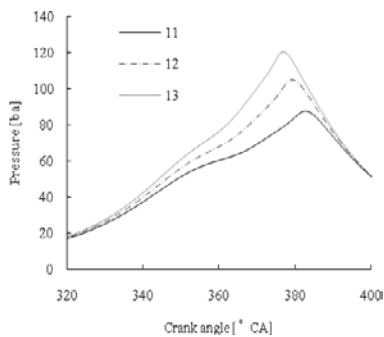
Table 3: The Main Turbulence Parameters around the Plug at 20°C BTDC

Compression ratio	11	12	13
Turbulence Kinetic energy ( m2/s )	34.7	34.7	36.3
Flow velocity ( m/s )	2.42	2.54	2.65
Integral length scale ( m )	0.00496	0.00492	0.00488

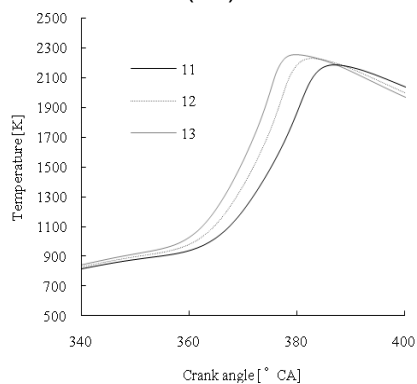
Figure 12 shows the in-cylinder parameters under different compression ratios at 1900r/min-1800Nm. The higher the compression ratio, the faster the combustion heat release, the higher the boost pressure, and the maximum temperature in the cylinder. Compared to 11, the maximum instantaneous heat release rate, the highest pressure and the maximum temperature raise by 3.2%, 38.1% and 25.9% respectively when the compress ratio raises to 13. In this paper, we focus on the potential of improving the thermal efficiency, so the compression ratio 13 is chosen to used in E40 in the following experiment.



( b )



( a )



( c )

Figure 12: Pressure, Heat Release and temperature at 1900r/min, 1800Nm

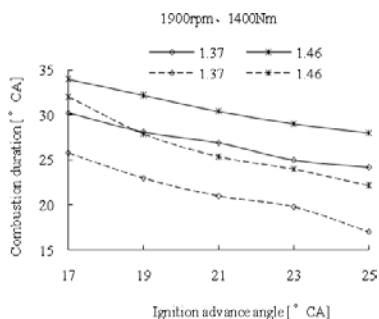


### IV. EXPERIMENTAL RESULTS

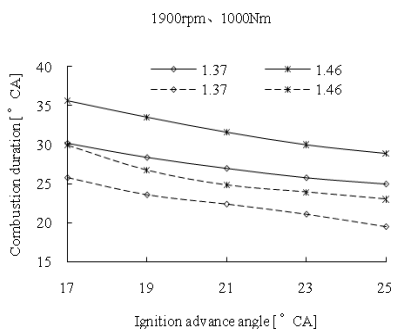
In the test research, in order to optimize the performance, the boost pressure, excess air coefficient, ignition advance angle are carefully chosen for each working condition, the comparisons of the experimental results between original cycle and miller cycle are given below.

a) *Combustion Duration*

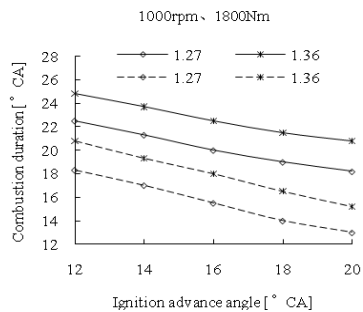
Figure 13 shows the comparison of the combustion duration (10%~90%) which varies according to the excess air coefficient and the ignition advance angle. It can be seen that the Miller cycle has a shorter combustion period. At 1900r/min, the combustion duration of the Miller cycle is about 5°C shorter; at 1000rpm, the combustion duration of the Miller cycle is about 4°C shorter.



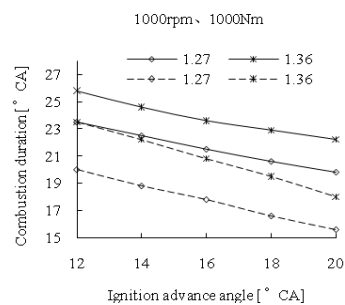
( a )



( b )



( c )

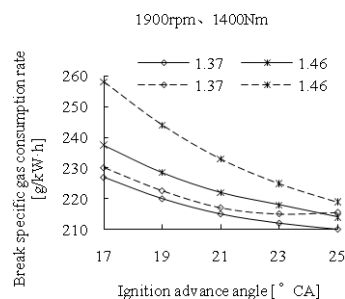


( d )

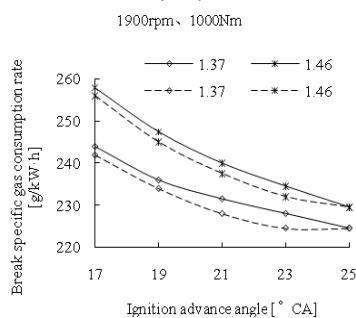
Figure 13: Comparison of the Burning Duration

b) *The Performance of Miller Cycle*

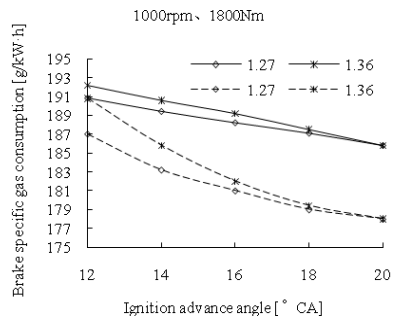
Figure 14 shows the comparison of the break specific gas consumption, at 1900r/min, when the load is above 1400Nm, due to the lower volume efficiency and more residual gas, the miller cycle has a higher gas consumption; under 1400Nm, miller cycle has a less gas consumption because of the reduction of cycle charge, At 1000r/min, the specific gas consumption of miller cycle obviously decreases, about 7~8g/kw.h.



( a )



( b )



( c )

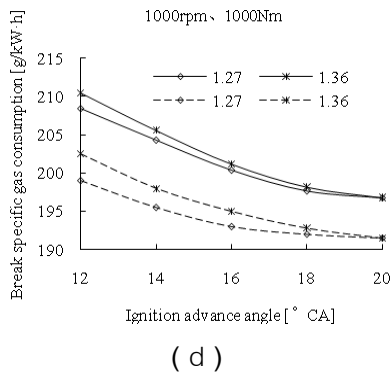


Figure 14: Comparison of Break Specific Gas Consumption

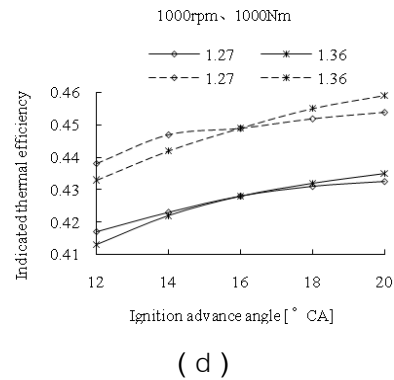
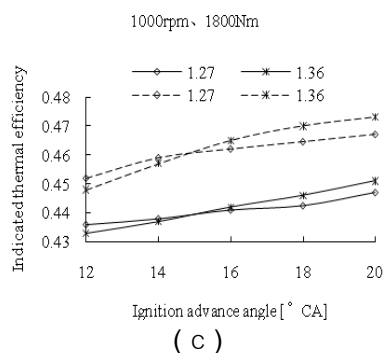
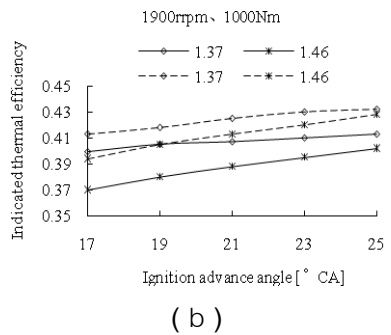
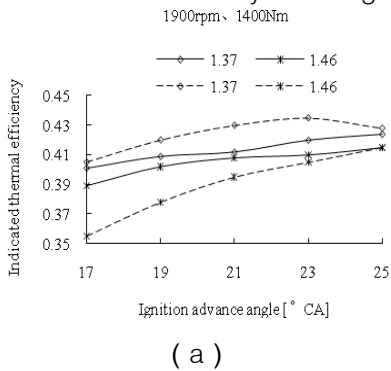


Figure 15: Comparison of Thermal Efficiency

Figure 15 shows the comparison of the thermal efficiency. At high speed condition, thermal efficiency doesn't have much difference, but at low speed condition, The thermal efficiency of the Miller cycle is about 5~7% higher, the maximum thermal efficiency of the Miller cycle reached 47%, the increase of thermal efficiency is mainly caused by the higher compression ratio, while the residual gas coefficient has great influence on the thermal efficiency of the high speed.



## V. CONCLUSION

The simulation calculation of the Miller system which combines EIVC with higher compression ratio is carried out, and the heat release process is investigated in detail, according to the calculation results, the optimization scheme is selected and put into experimental study. Compared to the original cycle, the optimization scheme has the following characteristics:

- 1) the pumping loss is slightly lower.
- 2) the heat release is relatively concentrated and rapid, the combustion center is about 5 °CA earlier, and the time for the combustion duration decreases by 5 °CA, so the thermal efficiency increases.
- 3) The break specific gas consumption of the middle and low speed improves obviously, but in the condition of high speed and heavy load, it is deteriorated due to the increase of the residual exhaust gas.

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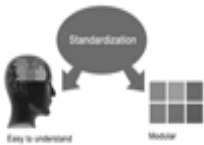




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**Note :**

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- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
- In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
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### Author Guidelines:

1. General,
2. Ethical Guidelines,
3. Submission of Manuscripts,
4. Manuscript's Category,
5. Structure and Format of Manuscript,
6. After Acceptance.

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- (g) Discussion should cover the implications and consequences, not just recapitulating the results; conclusions should be summarizing.
- (h) Brief Acknowledgements.
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- One should start brainstorming lists of possible keywords before even begin searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in research paper?" Then consider synonyms for the important words.
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- One should avoid outdated words.

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#### References

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**1. Choosing the topic:** In most cases, the topic is searched by the interest of author but it can be also suggested by the guides. You can have several topics and then you can judge that in which topic or subject you are finding yourself most comfortable. This can be done by asking several questions to yourself, like Will I be able to carry our search in this area? Will I find all necessary recourses to accomplish the search? Will I be able to find all information in this field area? If the answer of these types of questions will be "Yes" then you can choose that topic. In most of the cases, you may have to conduct the surveys and have to visit several places because this field is related to Computer Science and Information Technology. Also, you may have to do a lot of work to find all rise and falls regarding the various data of that subject. Sometimes, detailed information plays a vital role, instead of short information.

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**24. Never copy others' work:** Never copy others' work and give it your name because if evaluator has seen it anywhere you will be in trouble.

**25. Take proper rest and food:** No matter how many hours you spend for your research activity, if you are not taking care of your health then all your efforts will be in vain. For a quality research, study is must, and this can be done by taking proper rest and food.

**26. Go for seminars:** Attend seminars if the topic is relevant to your research area. Utilize all your resources.



**27. Refresh your mind after intervals:** Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

**28. Make colleagues:** Always try to make colleagues. No matter how sharper or intelligent you are, if you make colleagues you can have several ideas, which will be helpful for your research.

**29. Think technically:** Always think technically. If anything happens, then search its reasons, its benefits, and demerits.

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**33. Report concluded results:** Use concluded results. From raw data, filter the results and then conclude your studies based on measurements and observations taken. Significant figures and appropriate number of decimal places should be used. Parenthetical remarks are prohibitive. Proofread carefully at final stage. In the end give outline to your arguments. Spot out perspectives of further study of this subject. Justify your conclusion by at the bottom of them with sufficient justifications and examples.

**34. After conclusion:** Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print to the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects in your research.

## INFORMAL GUIDELINES OF RESEARCH PAPER WRITING

### Key points to remember:

- Submit all work in its final form.
- Write your paper in the form, which is presented in the guidelines using the template.
- Please note the criterion for grading the final paper by peer-reviewers.

### Final Points:

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

The introduction will be compiled from reference matter and will reflect the design processes or outline of basis that direct you to make study. As you will carry out the process of study, the method and process section will be constructed as like that. The result segment will show related statistics in nearly sequential order and will direct the reviewers next to the similar intellectual paths throughout the data that you took to carry out your study. The discussion section will provide understanding of the data and projections as to the implication of the results. The use of good quality references all through the paper will give the effort trustworthiness by representing an alertness of prior workings.





Writing a research paper is not an easy job no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record keeping are the only means to make straightforward the progression.

**General style:**

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear

- Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page
- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

- Use standard writing style including articles ("a", "the," etc.)
- Keep on paying attention on the research topic of the paper
- Use paragraphs to split each significant point (excluding for the abstract)
- Align the primary line of each section
- Present your points in sound order
- Use present tense to report well accepted
- Use past tense to describe specific results
- Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives
- Shun use of extra pictures - include only those figures essential to presenting results

**Title Page:**

Choose a revealing title. It should be short. It should not have non-standard acronyms or abbreviations. It should not exceed two printed lines. It should include the name(s) and address (es) of all authors.



## Abstract:

The summary should be two hundred words or less. It should briefly and clearly explain the key findings reported in the manuscript-- must have precise statistics. It should not have abnormal acronyms or abbreviations. It should be logical in itself. Shun citing references at this point.

An abstract is a brief distinct paragraph summary of finished work or work in development. In a minute or less a reviewer can be taught the foundation behind the study, common approach to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for brevity. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

- Reason of the study - theory, overall issue, purpose
- Fundamental goal
- To the point depiction of the research
- Consequences, including definite statistics - if the consequences are quantitative in nature, account quantitative data; results of any numerical analysis should be reported
- Significant conclusions or questions that track from the research(es)

## Approach:

- Single section, and succinct
- As an outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an abstract must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

## Introduction:

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from an abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

## Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.



- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

#### **Procedures (Methods and Materials):**

This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

#### **Materials:**

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

#### **Methods:**

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

#### **Approach:**

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

#### **What to keep away from**

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

#### **Results:**

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently. You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.



## Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

### What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

### Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

### Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

### Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

### Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.



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	A-B	C-D	E-F
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<i>Introduction</i>	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
<i>Methods and Procedures</i>	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
<i>Result</i>	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
<i>Discussion</i>	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
<i>References</i>	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring



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