Electro-Pneumatic Multi-Level Suspension System for All Terrain Vehicles (ATVs)

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Abstract: This research corresponds to reducing the inherent limitations with conventional suspension system of having fixed rate damping function. A new technique is introduced which can effectively make conventional systems more adaptive to terrain shifts. It uses an integrated electro-pneumatic hardware sense and control mechanism. A broad spectrum operation is ensured by having real time control over damping rate thereby implicitly changing the overall suspension stiffness automatically in real time when the vehicle is moving. This system can very conveniently be used in place of the conventional suspension systems of the vehicles.

Key Words: Suspension, Electro-Pneumatic Control, Fuzzy Logic, All Terrain Vehicles.

I. INTRODUCTION

The suspension system of any moving structure is the most fundamental component of the whole chassis structure. The way it has been designed implemented and determines vehicle's overall maneuverability and characteristics when presented to stress under dynamic conditions. The function of a suspension system primarily in a vehicle is to: (a) Stabilize the structure when the vehicle encounters uneven terrain surfaces (bumps and dips). (b) Aid in enhancing the lateral grip when the vehicle maneuvers (acceleration, braking or cornering). Suspension systems conventionally use various mechanical techniques to satisfactorily perform the required functions. The most important segment of this system is the spring-damper strut, used as a compensator for the jerks (oscillations) transferred to the drive cabin from rough road surfaces. Dampers perform two actions; one is to minimize the crude response of springs to oscillate when compressed or stretched by an external force. Dampers use multiple techniques to perform the required damping action. Oil filled dampers are commonly used due to their satisfactory results and availably**.** They rely on the fluidic characteristics of the oil filled inside them, but this also serves as a limitation to their functionality. The compression/rebound rate is linearly connected with what velocity the damper piston travels when it is compressed or stretched (Figure 1). The ratio by which it performs this action (proportionality) is known as the Damping Coefficient. It depicts the whole response curve of how a damper will perform along its entire working span. This rate is fixed for each damper, which makes them compatible for only a certain type of road/terrain condition.

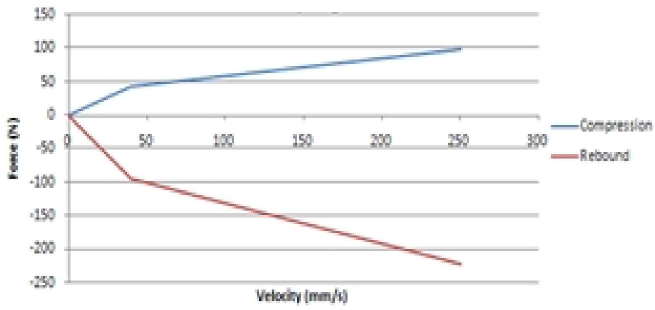


Figure 1 Resisting force Vs velocity of travel, of a generalized damper

II. Electro-Pneumatic Suspension System

A solution to enhance the functionality of a suspension system is by using an electro-pneumatic control system which makes the ability to change damping characteristics in real-time possible. This makes a vehicle adaptive to sudden terrain variations. This system uses the phenomenon of oil viscosity changes under compression (Figure 2). It has a number of advantages over conventional dampers being used. Such dampers inherently have fixed damping characteristics and only perform best under predefined road conditions (as designed by manufacturer) [1] [2]. This serves as a limiting factor to the adaptability of a vehicle when given uncertain road conditions.

This system uses Remote Reservoir Gas Dampers, operated by a control system. These dampers have a dedicated gas chamber connected with the main cylinder, and oil can flow through both these chambers. The gas chamber has an air bladder, in which when pressurized air is filled, it simply expands. As the bladder is enclosed in the chamber and is surrounded by oil, expansion causes the oil to compress thus making it more viscous, and making the damping rate stiffer. This phenomenon is used as the basic far end for implementing a multi-level suspension system [3].

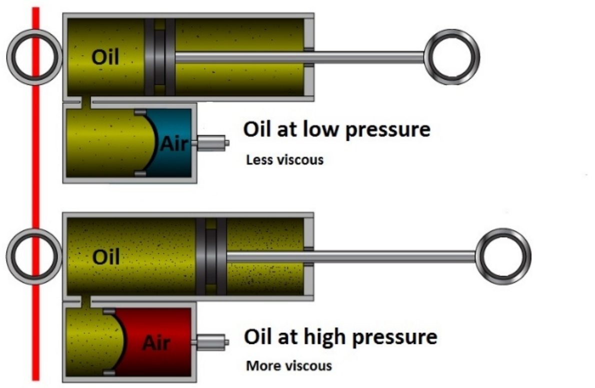


Figure 2 Illustration of oil compression by air inside a Remote-Reservoir Gas Damper

III. Hardware Design

The electro-pneumatic control system, when installed in a vehicle, calculates the vertical acceleration (oscillations) being produced in real-time, and then opts for the best suited stiffness settings to meet the demands of the road [4] [5].

The system works in such a way that strut tower of each wheel is installed with a remote reservoir gas damper. Four valves control the air flow from either the accumulator tank to the dampers or from the dampers to the atmosphere (Figure 3). Pressure of 80 to 110 psi is maintained in the accumulator tank by an air charging pump. The backbone of this control is microcontroller which monitors the gas pressure of the accumulator tank and the dampers by pressure transmitters. Road conditions are quantified in terms of oscillations picked up in the drive cabin by an accelerometer. This system has three different modes of operation from which the driver can select the most appropriate one suiting his requirements. This is to ensure a broad spectrum addressing of all the possible conditions a vehicle could face on its course. To manipulate the stiffness, system controls the pressure inside these dampers. To increase the pressure, the system lets more air flow from the accumulator to the damper gas chambers. While air is bled to the atmosphere when the system has to decrease

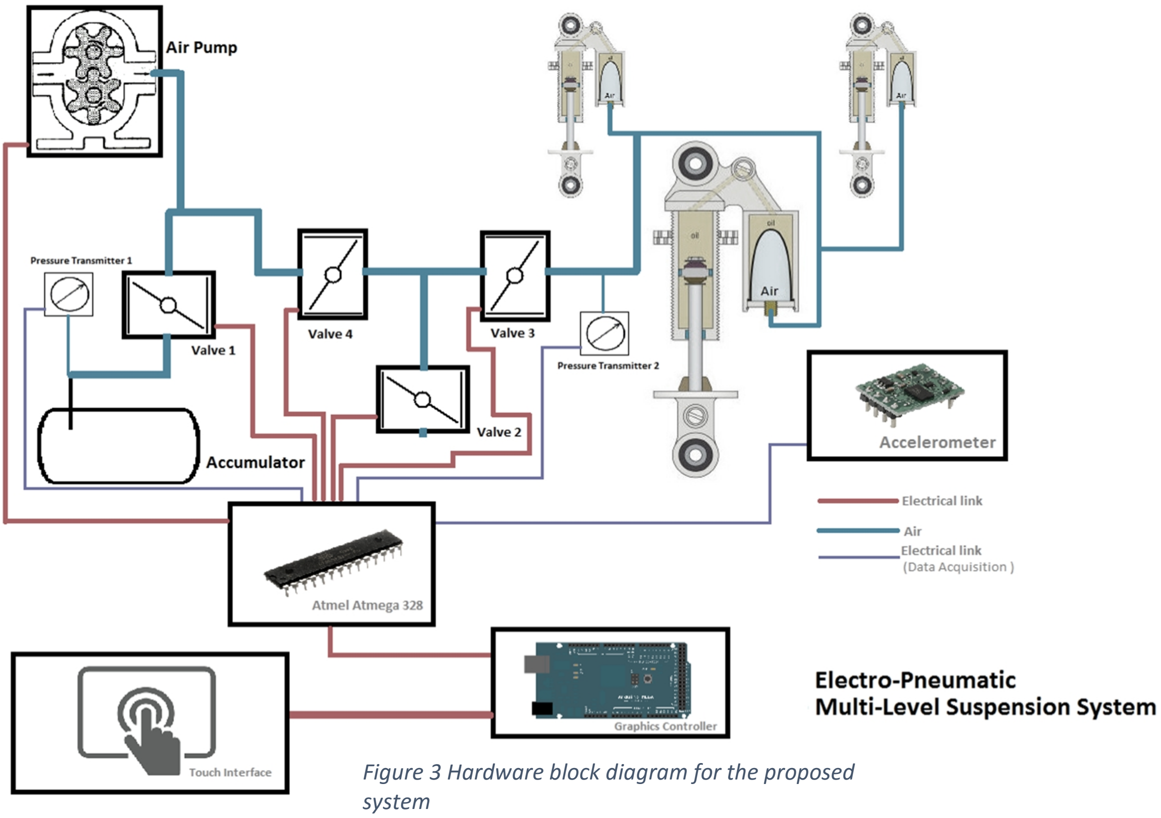


Figure 3 Hardware block diagram for the proposed system

the pressure inside the dampers. By this, the system implicitly controls how hard or soft the dampers should act according to the present road conditions [6] [7].

IV. Control Methodology

The designed system gives the driver command over three different types of modes on which it could function. These are (a) Comfort Drive (b) Sport Drive and (c) Manual Drive. These modes ensure that the vehicle can have the best suited suspension setting for the type of performance the driver desires.

A. Comfort Drive

This operational mode traces the present road condition from the input data from the accelerometer to provide the best suited damping rate according to the present terrain for more comfort in the drive cabin. It constantly monitors how the drive cabin is reacting to the present settings and adjusts the stiffness every time it senses oscillations in the drive cabin over a threshold limit. This methodology ensures that as the road conditions change the suspension readily shifts to a more compatible level to deliver a comfortable ride.

```
-Ignition switch on
-Read Sensors
-If (accelerometer/pressure transmitter output out of defined range?)
{
 -Notify driver interface for trouble code
}
-Read mode selection pins from driver interface for determining the desired mode
-Set pressure (50psi)
-If (Comfort Drive selected)
{
  -While (Comfort Drive selected)
  {
    -Read Accelerometer
    -If (oscillations < = 10%)
    {
      -Set pressure (+5psi)
    }
    -Else
    {
      -Set pressure (-5psi)
    }
  }
}
```

This fuzzy logic based algorithm makes the electro-pneumatic control system very adaptive to random terrain changes. Parameters like *pressure variation per sweep* (set to ±5psi) can be adjusted for any particular type of vehicle this system is being set up for.

B. Sport Drive

The Sport drive mode when engaged, enhances wheel traction and aids in lateral grip by reducing vehicle roll [8] and pitching [9]. This is achieved by stiffening up the dampers as the vehicle *brakes, accelerates or corners.* The accelerometer in this mode measures the lateral forces acting on the drive cabin to monitor vehicle movements. It the vehicle begin to roll on one side or changes its pitch, the system kicks in and controls the damping rate to counter this action.

```
-Ignition switch on
-Read Sensors
-If (accelerometer/pressure transmitter output out of defined range?)
{
 -Notify driver interface for trouble code
}
-Read mode selection pins from driver interface for determining the desired mode
-Set pressure (70psi)
-If (Sport Drive selected)
{
 -While (Sport Mode selected)
 {
   -Read Accelerometer in a loop
   -If (Accelerometer indicates roll)
   {
     -While (Accelerometer indicates roll)
     {
       -Set pressure (90psi)
     }
   }
   -Else If (Accelerometer indicates pitching)
   {
     -While (Accelerometer indicates stabilization)
     {
       -Set pressure (100psi)
     }
   }
 }
}
```

C. Manual Mode

The manual mode lets you independently set wheel travel stiffness setting from the driver interface. This mode is primary focused to enhance off-roading capabilities of vehicle where the driver has the ability to pre-set the suspension parameters as the terrain demands. The driver interface sends the desired stiffness level encoded in 4-bits data to the microcontroller. Along with this, the system also warns the driver if suspension is set too soft and may cause suspension bottoming out [10]. Furthermore, the system also monitors the suspension performance in the current settings and informs the driver through the interface, making it useful for calibration of the other two modes.

V. Results

This system was implemented on a quad bike with the discussed methodology for testing. For the comfort drive mode, a straight path of 280m was chosen with the first 100m paved tarmac, following 80m of gravel, then 40m of a broken road patch, then 60m of again paved tarmac. The quad bike was kept constantly at 30km/h throughout the track. The accelerometer measured the amplitude of oscillations experienced by the chassis in the Z direction (Figure 4).

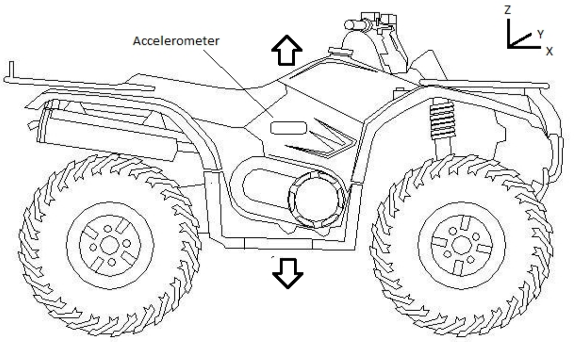


Figure 4 Illustration for direction of motion being sensed by the accelerometer in comfort drive mode: The system measures the travel in Z direction to determine chassis response on the present road condition.

Table 1 shows the recorded data from the accelerometer when the system not operating.

Time	Displacement*	Time	Displacement*
2 sec	3.02mm	20 sec	9.51mm
4 sec	3.10mm	22 sec	18.07mm
6 sec	3.08mm	24 sec	28.77mm
8 sec	3.13mm	26 sec	24.09mm
10 sec	2.98mm	28 sec	7.54mm
12 sec	8.93mm	30 sec	2.87mm
14 sec	10.17mm	32 sec	3.84mm
16 sec	9.76mm	34 sec	3.17mm
18 sec	10.05mm	36 sec	2.70mm

Paved Tarmac
Gravel
Broken Tarmac

*Displacement from mean position of the accelerometer

Table 1 Corresponds to vehicle traveling time Vs magnitude displacement of vehicle traval in Z direction (Refer to Figure 4 for axis details). It depicts a quantative measurment of osciallations being experienced by the chassis in terms of vertical travel from the mean position as the terrain changes.

Table 2 shows the recorded data when the system is turned on and comfort drive mode is selected.

Time	Displacement*	Time	Displacement*
2 sec	2.87mm	20 sec	5.19mm
4 sec	3.31mm	22 sec	15.22mm
6 sec	3.41mm	24 sec	16.61mm
8 sec	2.95mm	26 sec	20.95mm
10 sec	3.71mm	28 sec	11.81mm
12 sec	9.67mm	30 sec	8.63mm
14 sec	7.84mm	32 sec	4.20mm
16 sec	6.90mm	34 sec	3.91mm
18 sec	7.21mm	36 sec	3.69mm

Paved Tarmac
Gravel
Broken Tarmac

*Displacement from mean position of the accelerometer

Table 2 Corresponds to vehicle traveling time Vs magnitude displacement of vehicle traval in Z direction with the Electro-Pneumatic suspension system working in comfort drive mode. The result shows a reduction in degree of oscillations measured by the chassis with the same testing conditions.

For testing the sport drive mode, the quad bike was made to perform a 'S' turn at 15km/h. The accelerometer measured the body roll (tilting) while performing this maneuver (Figure 5).

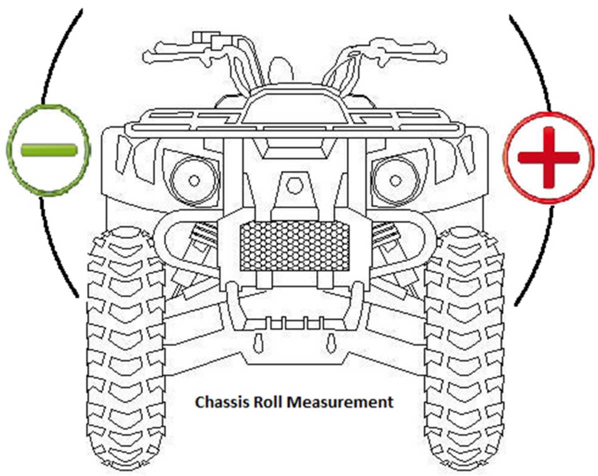
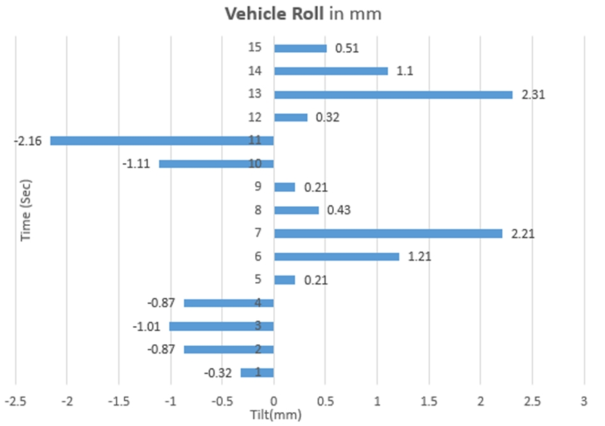


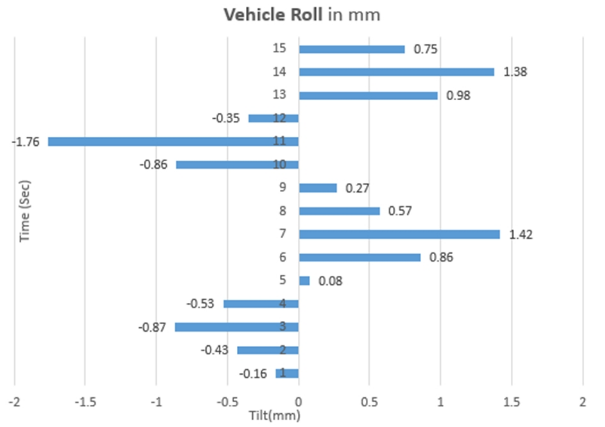
Figure 5 Shows the tilt being measured by the accelerometer in sport drive mode. Tilting to the right is set on the positive scale and left is set on the negative scale. It is measured in terms of angular displacement from the reference in mm.

Graph 1 shows the vehicle roll when the system is not operating.



Graph 1 Refers to vehicle travel time Vs chassis tilting. It shows the roll experienced by the chassis when the ATV was set to maneuver a S turn at constant speed.

Graph 2 shows the vehicle roll with the system turned on and sport mode selected.



Graph 2 Refers to vehicle travel time Vs chassis tilting with the Electro-Pneumatic suspension system working in sport drive mode. Comparision shows that the system has significantly reduced the vehicle roll.

VI. Conclusion

As the results depict, this electro-pneumatic multi-level suspension system can very effectively adapt to random terrain changes. The system has a quick response time and can significantly reduce the oscillations any chassis has to face with rough road conditions. The inherit limitation in a conventional suspension setup of having fixed rate damping action can be reduced by application of this method. It can be scaled to be installed in all types of vehicles, giving them the ability to be used in all types of road conditions. Picture 1 & Picture 2 shows the actual prototype quad bike installed with this sytem.

Picture 1 ATV vehicle installed with Electro-Pneumatic Suspension control system.

Picture 2 Remote Reservoir Gas Damper installed in the ATV with high pressure air-line connected.

A very noticeable advantage of such a system is the versatility of operation as the vehicle installed with it can be comfortable and can have good handling at the same time. This can relatively be far more complex to achieve with any conventional suspension system.

VII. References

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VIII. Definitions

[8] Vehicle Roll: On wheeled or tracked vehicles, roll is a reference to the load transfer of a vehicle towards the outside of a turn.

[9] Vehicle Pitch: the nose of the vehicle goes up and the back goes down, or vice versa.

[10] Suspension Bottoming: It is the tendency of the Spring-Damper Strut to collapse (compress fully) under sudden stress due to low stiffness of the spring or damper, virtually making the vehicle hit the ground.