Design of an automatic tyre pressure inflation system for small vehicles

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Abstract

The advent of the tyre/automotive industry brought to a halt the savage days of long journeying by foot and suddenly introduced quick inter-city visits whilst the traveler is seated. In a bid to improve and perfect this modern way of journeying this paper focuses on the optimization of the automobile, subject matter being the effective and proper maintenance of the tyre so as to curb the disappointment of failing to travel due to underinflated tyres. The design presented in the report herein functions to restore the tyre pressure on vehicles so that they are kept at optimum pressure levels, thus extending their life time at the same time saving the owner from fuel costs and maintenance cost incurred with underinflated tyres. It constitutes of a wind driven turbine-compressor unit which uses drag wind as source of drive to a turbine and quickly converts it to rotational energy which powers a small compressor that feeds the tyre with pressurized air whenever the need arises. The system is monitored and controlled by a Java/Android program which detects low pressure and initiates compressor ON / OFF states. The system is environmentally friendly releasing zero gases and is self-sustaining using independent power source from that of the vehicle itself.

Keywords

Design, automatic, tyre pressure, inflation system, small vehicles

1. Introduction

As such it has also prompted the use of tyres, which according to studies carried out are the second highest operating cost the vehicle after fuel. It has also been adverted by the Technology and Maintenance Council (TMC) of America that 53.5 percent of road-side breakdowns were caused by tyre problems and also that tyres were the second leading causes of inspection citation after brakes (TMC S.2 Tire and Wheel., 2010). Furthermore the cost of fuel and tyres has significantly increased in the past years, yet the general majority of drivers doesn't know that proper and timely pressure inflation or pressure management systems can lead to great cuts on maintenance and fuel costs as shown by the research done by the North American Council for Freight Efficiency (NACFE, 2013), that improperly inflated tyres can lead to the vehicle taking more than necessary fuel when in operation due to promoted retardation since underinflated tyres increase the drag force on a vehicle. Improper tire inflation also leads and promotes treads which simply ensues from increased rolling resistance as referred to by the Goodyear article on Tyre Pressure Monitoring Systems (Dr.Benedict, 2012), it has been stated in researches by the TPMS (TMC S.2 Tire and Wheel., 2010) that under inflation of tyres by 20 percent increases treading by 25 percent and reduce the tyre life by 30 percent, 10 percent over inflation reduces treading by 5 percent due to the uneven abrasion of the tires against the road. A proper and automated pressure inflation system would eliminate both the problem of cost and improper inflation since it is censored with the adequately necessary pressure levels depending on tyre condition. This would in turn preserve the tires as well as the fuel (van Zyl, 2013).

1.1 Background

There has been a notably increasing number of inconveniences let alone untimely expenses caused by tyre problems, including and not limited to increased fuel consumption. Majority of scenarios have been where one fails to make it to work or to an appointment in time due to a flat tyre and on top of that is forced to fish out money to get the car operational again simply due to tyre pressure issues (Varghese, 2013). Many drivers do the routine of passing through a pressure refilling point every morning before they get to work which is a both inconvenient and expensive way to maintain tyres, and as such some drivers choose to ignore under inflated tires (Omprakash & Kumar, 2014). Unfortunately they do not know that in doing so they increase the overall fuel consumption of the vehicle. The instauration of a proper and automated tire pressure inflation system would be an innovational advent that would answer to the many vehicle hustles related to tyre pressure systems currently being faced, incidentally reducing tyre repair costs by 28% according to Bradley (1997) as cited by (Pletts, 2006). The under-inflation of car-tyres attribute to high maintenance cost of the tyres, elevated fuel consumption and inconveniences or holdups to the user which has negative effects on finances and it causes delays to work and other appointments. The aim of the paper is to design an automatic tyre inflation system for tyre pressure monitoring and maintenance so as to improve the service provision to cost ratio of any sedan car as well as provide user comfortability and convenience.

2. Literature review

The motoring industry has seen automation of many parts of the automobile for enhanced service quality and performance (Omprakash & Kumar, 2014). Efficiency, convenience and safety as well as cost savings being top priorities of these automations thereby prompting attention to the tyre area which is the least automated yet a major cause of concern when discussing all the above mentioned attributes (Wang, et al., 2002).

2.1 Dynamics behind the automobile tyre system.

It is of great importance to carefully take into account the effect of high speeds on reciprocating machine elements in order to properly and adequately balance them out otherwise they would produce vibrations as with reference to the text by (Kottayam, 2002-2003, p. 1). These vibrations would in turn cause accelerated wear of components such as the bearings and worse still it may lead to complete machine failure or cause significant damage to both the machine and the ground that supports it (Randall, 2011). In this project the researcher therein focusses on the tyre area on an automobile which is reasonably responsible for vibration absorption and vehicle safety considering that it is the lone means of contact of the ground and the machine in question. The tyres and the automobile's suspension system have been designed with the capability to absorb vibrations from both the ground and the vehicle henceforth maintaining a balance of masses (Kottayam, 2002-2003) and thus keeping low response levels.

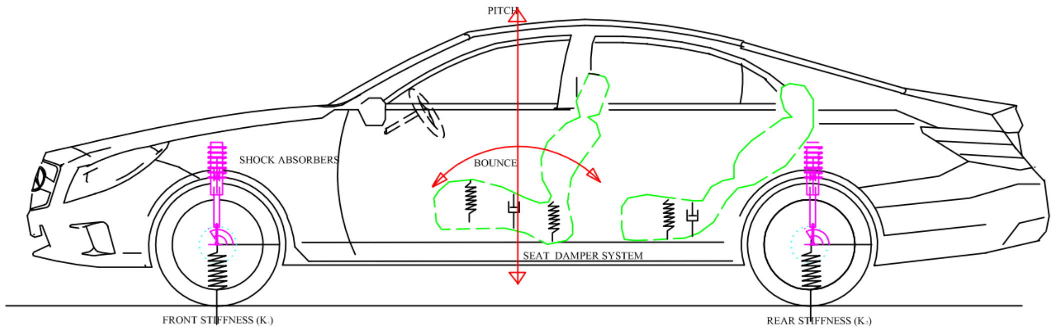

Figure 1. CAD Illustration of the pitch, bounce capability (Singiresu, 2011), p. 539.

An *Experimental Modal Analysis (setup shown in the diagram below)* is carried out on a vehicle during its production and the results are used to find the limiting levels of vibration absorption that is required and this information is used in the designs of vehicle tyres, determination of tyre sizes depending on overall load, both the NVM and the GVM values, and also in the design of the shock absorbers to allow for pitch and bounce (Beard & Sutherland, 1993).

The linking shock absorbers and leaf springs from the car suspension see to it that all the induced oscillations by the unevenness of a variable road-surface are safely isolated from the vehicle and dissipated away as per principles of vibration isolation (Singiresu, 2011). The tyres are made of resilient material (rubber) which provides grip and absorbs energy (Khurmi & Gupta, 2005) thereby preventing damage to the ground at the same time offering ride comfort. Overly these effects result to vehicle safety and optimum performance given that the tyres operate at the set optimum service pressure levels. The tyre is also tested for a *Finite Element Analysis* (Anghelache & Moisescu, 2008), to study its responses and mode shapes during operation for compressive stresses due to the weight of the car, the impact loading or shock loading when operating at NVM and at GVM. The analysis is done for shear stresses and bending stresses during breaking and turning of the car (Anghelache & Moisescu, 2008).

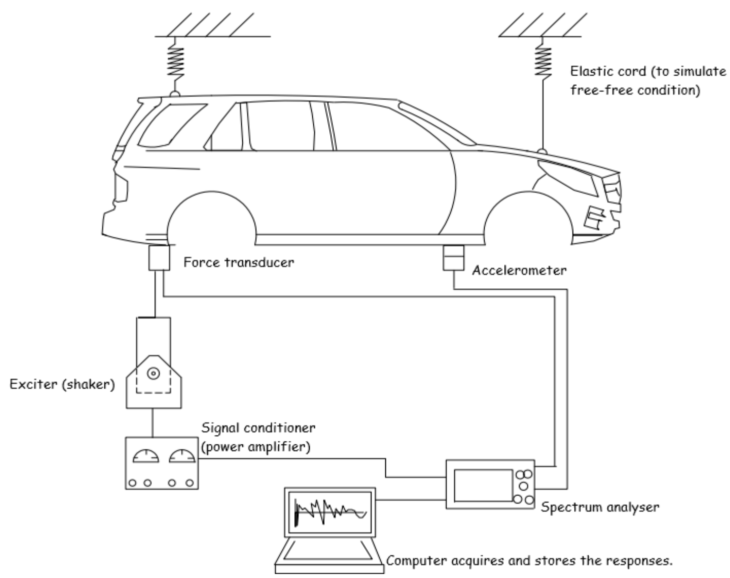

Figure 2. Experimental modal analysis. (Singiresu 2011, p.903.)

Thus so the proper monitoring and maintenance of tyre pressure would ensure that the vehicle operates within range of these stresses in the wind's viscous drag basing on drag effects (Douglas, et al., 2005, p. 430), eliminating the additional effect of the drag force of an underinflated tyre which would mean increased fuel efficiency, enhanced convenience, and tyre life longevity thus minimal maintenance or replacements costs.

2.2 Pressure influence on: vehicle performance; tyre life; fuel

The detail from the analysis discussed above is used in the dimensioning and structural outlay of the tyre, i.e. resilient material selection, size ratio with the vehicle, as well as optimum operating pressure levels. Effects of incorrect operating tyre pressure levels are shown by the picture below:

Figure 3. How tyres look like in different cases

3. Methodology

The researchers at this juncture will elaborate the methods that are going to be used in coming up with the automated pressure system for tyres, some of which will include the use of AutoCAD 2007 and Solid Works 2014 which are Computer Aided Design Packages to produce working drawings for the various components of the system, furthermore the assimilation of the sensor technology implementation by means of modelling using Android Studio 2.0 and Java SDK for coding.

3.1 Compressor units.

The compressor component is the one that will produce the required pressurised air, thus so its position will be critically considered since it will need to supply all wheels equally. The compressor unit/s also has to be powered by a secondary source other than the battery to avoid overloading.

3.2 Pipe-network / air carriage system.

This is the network of pipes which will actually carry the pressurised air to the wheels upon request conveyed by the respective sensor mechanism on the wheel. It will be short and delicately made in order to fit for rotating wheels, preferably it will be imbedded in main wheel assembly structures so as to avoid any chances of damage. These also should be strong so they can withstand the force due to pressurized air.

3.3 Delivery systems and valves.

This pertains to the small tubes which will connect to the tyre and deliver the air from tanks or compressor. The whole system will be made with a dense supply of self-actuating valves to ensure safe and efficient delivery of pressurised air to wherever it is purposed. One way valves/check valves to prevent backflow, quick relief valve for safety kill switches and controller/ regulator devices to keep the pressure constant.

3.4 Sensor mechanism / on – off switching.

Undoubtedly the most vital component of the system to be expertly engineered with precisely accurate pressure pre-set limits to initiate pressure supply On-state whenever the tyre has deflated to a value of pressure less than the provisional optimum boundary value $P_{opt-min}$ and Off-state whenever the tyre has gained enough pressure to value just below $P_{opt-max}$. The values $P_{opt-max}$ and $P_{opt-min}$ are values such that they are 0.3 bars plus and minus optimum tyre operating pressure respectively.

4. Results and discussion

The researchers then chose concept of wind turbine as the main focus to solve the tyre pressure problem. This is the wind driven compressor mechanism which will be mounted directly on the wheel of the car tyre area and will be operated remotely by the driver from the comfort of his/her seat in the driver's compartment.

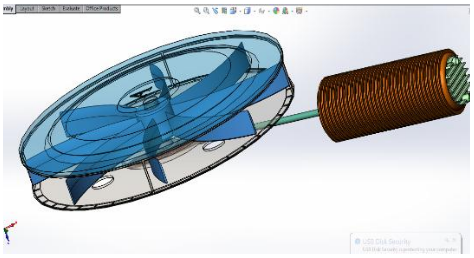

Figure 4. Turbine in place

4.1 **The wind driven compressor mechanism description**

The system comprises of a small wind turbine with 8 rotor blades of radial length R83mm (*due to the limited space on the wheel*) which is driven by the drag (wind) near the body of a speeding car. A speeding car will be cutting through a mass of wind which is in the opposite direction its motion. The kinetic energy in this mass of air is utilized in this design as it will function to turn the turbine thereby turning with it a small crank disk R40mm which is rigidly fixed to the turbine axis' rear. The crank - turn will push up and down in one revolution the piston rod thus achieving compression strokes directly. The piston - cylinder compressor is of size order: bore Φ30mm X stroke L80mm also due to the limited space on the wheel section. The compressed air will then be easily fed to the tyres via the outlet check valve (*one way calve*) to the sensor gauge which will then feed pressurized air to the tyre. The design calculations have been modelled into a (*spreadsheet program*) system which is quickly adjustable to modify calculations so they may suit any type of passenger car with different specifications from the ones sampled for the purposes of this design report.

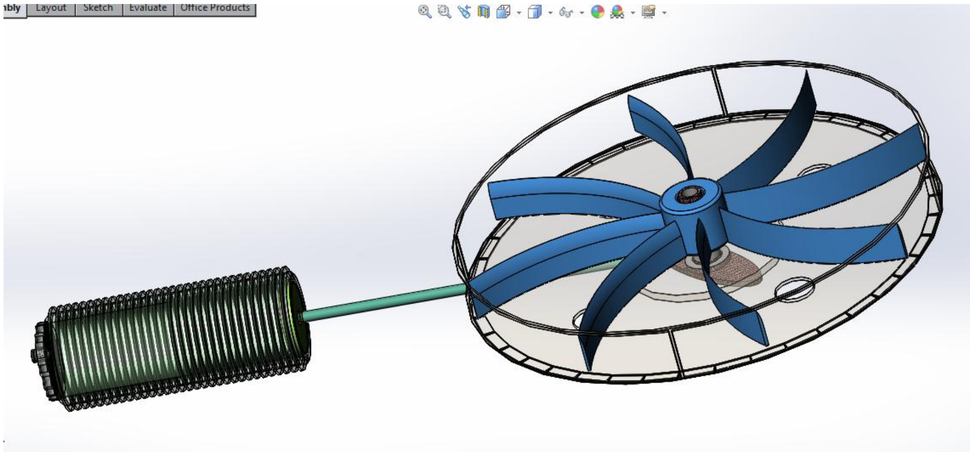

Figure 5. Crank cam at the rear of the turbine unit

4.2 **Turbine design**

The rotor blades of the turbine have been sized to 83mm each for a total number of eight blades. The turbine will be the horizontal axis type. For a car moving at 25km/hr (*25km/hr because the researcher chose to start from the safe speed limit around the University roads and other Company grounds*) the wind on the immediate surface or body of the car theoretically has the same speed in the opposite direction for a calm day, such that: V_{wind} = 25km/hr.

Therefore: $V_{wind} = \frac{25 \text{ x } 1000}{60 \text{ } X \text{ } 60} = \underline{6.944\text{m/s}}$

Now from (*citation*) the density of air is 1.225kg/m^3 on a car with the drag of $C_d = 0.36$ and frontal area 1.70m^2. The drag force of this mass of wind:

$F_d = ½.\rho.A.C_d.v^2$ and thus power in the wind which is

$P = F_d \text{ x } v$ becomes $= ½.\rho.A.C_d.v^3$

$P_{wind} = 0.5 \text{ x } 1.225 \text{ x } 1.70 \text{ x } 0.36 \text{ x } 6.944^3$

$= \underline{125.5 \text{ Watts.}}$

From this power of wind now by Albert Betz (Ragheb, 2014) a maximum of about 0.59 of the wind power is usable and for mechanical systems a practical conversion of about 0.4 is usable therefore the power in the turning turbine will be:

$P_{turbine}$ = 0.4 x P_{wind} = 0.4 x 125.5 = 50.2 Watts.

Therefore the deliverable power to the compressor by the rotor is 50.2Watts provided the speed of the car is a constant 25km/hr.

Speed of the rotor blades/turbine:

Area Swept by turbine rotor blade is A_1. $A_1 = \pi (R_1)^2$ due to the limited space of installation of the system a singular rotor blade of the turbine is to be made with a radius of 83mm and it is to be selected as of the S – 818 Aerofoil profile which is the most efficient of the profiles.

$A_1 = \pi (0.083)^2 = 0.0216m^2$

Power of a rotor turbine is given by $P_{rotor} = ½.\rho.A_1.(v_r)^3 = P_{turbine}$

From above calculation we found that $P_{turbine}$ = 50.2 Watts hence P_{rotor} = 50.2 Watts. Thus:

$50.2 = ½ \times 1.225 \times 0.0216 \times (v_r)^3$ $(v_r) = \{50.2 / (1/2 \times 1.225 \times 0.0216)\}^{1/3}$

v_r = 15.587m/s and by $\omega = v/R_1 = (15.587/0.083)$

= 29.89 rps (revolutions per second).

Which will directly translate to be the speed of the piston of the small compressor since the rod is rigidly fixed to the back of the turbine.

Torque of the turbine:

P = Tω wherefore ω = 2 π N where N is in revs/sec

T = P/ω. Which therefore can be substituted to obtain

= (50.2/[2 x π x 29.89]) = 0.2673 Nm All the values for the torques of the different conditions sampled have been enclosed in the appendix.

Radius of curvature – (R) = 83mm. Pieces x 8 circular arrayed rigidly fixed to a small circular disk with diameter 80mm.

4.3 The axis of the turbine:

Adopting the simulations from the Savonius Wind turbine design (Babalas, et al., 2015) which portrays the same blade layout as that used in this design. The study done on this turbine showed that wind at 293.2K with speeds of 27m/s by simulations had a blast force of 169.1N.

Table 1. Properties of SteelC45

	Mechanical Characteristics	Parts of Use
Steel C45	Tensile Strength: 600-800 MPa	Axis
	Yield Strength: 340-400 MPa	Support rings
	Shear Stress: 450-600 MPa	Supporters of the base
	Tensile Modulus: 190-210 GPa	Side to side cylinder
	Poisson's Ratio: 0.27-0.30	Bases

The design considerations in this report can safely adopt these values for safe design since the maximum speed limit of the system will be 85 km/hr and pressure 101325 N/m^2 which is safe driving limit for highways. This translates to 23.6m/s and design temperature

$T_{average}$ = (28.141667 + 15.680556)/2

= 21.91 i.e. 273.15 + 21.91 = 295.06K which is comparable.

For the point of support which is at the end of 30mm: Moment M = 169 x 0.03 = 5.07 Nm. Torque at 85km/hr from (*excel spreadsheet*) Appendix 1: = 3.091Nm. Using safety factor of 3. The diameter of the axis should be at least:

$$D = \left\{\frac{32 \times N}{\pi * \tau}\sqrt{M^2 + \frac{3}{4}T^2}\right\}^{\frac{1}{3}} = \left\{\frac{32 \times 3}{\pi * 340 \times 10^6}\sqrt{5.07^2 + \frac{3}{4}(3.091)^2}\right\}^{\frac{1}{3}}$$

D = 0.0080m which is 8mm then a standard 10mm was used.

The system has a lever that pushes the turbine vent assembly outward when the compressor is active and feeding pressurised air to the tyre. This is so that the blade unit is well exposed to the drag and that it maximises the power in the relative wind thereof. As such is also the purpose of the large disc cover in the diagram below to function as a protective cover so that there is no turbulence from the air currents hitting the dip of the wheel.

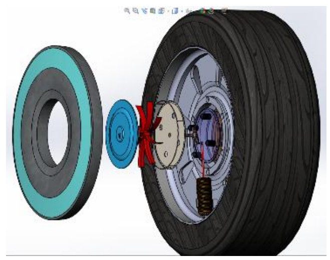

Figure 6. Complete system in operation

5. Recommendations and conclusions.

The manufacture of the system components requires highly skilled technical team since it involves the making of very small components by virtue of the position and point of application of the system. As such it is recommended that such technical experts should be responsible of building the system. The researchers also recommends the regular maintenance of the system's main components for continued functionality. The control of the system is fully automated and requires the driver's compliance to the speed limit messages on the display of the system control panel but does not give the operator overall control of the system which may cause discomfort to some motorists so as a recommendation the researcher would recommend further development of the rather less useful but sometimes needed manual control buttons. Due to lack of adequate design softwares for the Java/Android code the researchers could not further develop the machine code to a more appealing interface to the operator so it is recommendable for further development of the source code into a more inviting and colourful panel of output input messages.

The designers also recommends the further development of this system into a functioning prototype to illustrate the functionality of the design therein and its relevance to the tyre pressure maintenance.

5.1 Conclusion.

The use of vehicles as a mode of transport is notably growing by day and the ultimate goal of the engineering discipline would be to ensure satisfactory service provision. Proper and efficient tyre pressure maintenance is one of the answers to such endeavor and as such this design project contribute an idea that can be implemented and be of great savings to motorists. The design shows promise that once employed of fulfilling the objectives of this project of cost savings and ensuring convenience of the motorist.

Acknowledgements

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Biography

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APPENDICES

APPENDIX 1. Java android code

File - C:\Users\allantaku\JAVA\#Project android app\UZtps.java

```
import java.util.Scanner;

class UZtps{

static double Pturbine(int Speedcar,double Pintake){

    /* Speed of car = speed of the wind thus power in wind can be obtained by the method below */
        double mps = ((Speedcar/*km/hr*/*1000)/(60*60));
        double Pwind = 0.5*1.225*1.7*0.36*Math.pow(mps,3);
        double Pturbine = Pwind*0.4*0.85;
    // Power delivered by the Turbine to the Compressor unit.
        double p = Pturbine/(0.5*1.225*0.021642431);
        double v = Math.pow(p,(0.33333333333));
        double N1 = v /(0.083*Math.PI*2);
        double N2 = N1*(0.040/0.083);
    // The crank speed of the Compressor unit.
        double Vc = 6.36173*Math.pow(10,-07);
        double V1 = 5.71848*Math.pow(10,-05);
        double m = (264000/Pintake);
        double V4 = Vc*Math.pow(m,0.769230769);
        double Vs = V1-V4;
        double Pcompressor = 4.333333333*Pintake*Vs*((Math.pow(m,0.23076923))-1)*N2;
    // The power required by the Compressor to achieve compressor of pressure to deliver 264000 pascals.
    double SPEED = 85;
        if((Speedcar < 85) && (Pturbine < Pcompressor)){

            while(Pturbine < Pcompressor){
            mps = ((Speedcar/*km/hr*/*1000)/(60*60));
            Pwind = 0.5*1.225*1.7*0.36*Math.pow(mps,3);
            Pturbine = Pwind*0.4*0.85;
    // Power delivered by the Turbine to the Compressor unit.
            p = Pturbine/(0.5*1.225*0.021642431);
            v = Math.pow(p,(0.33333333333));
            N1 = v /(0.083*Math.PI*2);
            N2 = N1*(0.040/0.083);
    // The crank speed of the Compressor unit.
            Vc = 6.36173*Math.pow(10,-07);
            V1 = 5.71848*Math.pow(10,-05);
            m = (264000/Pintake);
            V4 = Vc*Math.pow(m,0.769230769);
```

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```
            Vs = V1-V4;
            Pcompressor = 4.333333333*Pintake*Vs*((Math.pow(m,0.23076923))-1)*N2;
    // The power required by the Compressor to achieve compressor of pressure to deliver 264000 pascals.
        Speedcar++;
            System.out.println(" ");
            System.out.println(" ");
            System.out.println("   TURBINE POWER
             = " + Pturbine + " WATTS ");
            System.out.println("   RATE OF COMPRESSION
         = " + N2 + " rps ");
            System.out.println("   DESIRED COMPRESSOR POWER  = " + Pcompressor + " WATTS ");
            System.out.println("   @ DRIVE SPEED
             = " + Speedcar + " km/hr ");}

        SPEED = Speedcar++;
        System.out.println(" ");}

    else if((Speedcar < 85) && (Pturbine > Pcompressor)){
    System.out.println(" ");
    SPEED = Speedcar;
    System.out.println(" MAINTAIN " + SPEED + " km/hr !!");}

    else if((Speedcar > 85) && (Pturbine < Pcompressor)){
    System.out.println(" ");
    System.out.println(" SLOWDOWN TO INITIATE SAFE COMPRESSOR TO ATLEAST" + SPEED + " km/hr " );}

    return SPEED;}

    public static void main(String[] args){
    System.out.println(" ");
    System.out.println(" ");}
    }
```

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```

class UZTPIS{

static double UZTPIS(double Ptr){
    UZtps pa = new UZtps();
    double Po = 240000;
    double d = 0;
    double error = Po - Ptr;
/* The if below receives data of CarSpeed and Compressor Intake Pressure from the pressure sensor
and windspeed sensor.
 */

/* CODE A */if(error >=30000){

            d = pa.Pturbine(25,99230);
            System.out.println(" TYRE PRESSURE IS LOW!! ");
            System.out.println(" ");
            System.out.println(" THE TYRE NEEDS " + error + " pascals ");
            System.out.println(" ");
            System.out.println(" TYRE PRESSURE IS LOW!! ");
            System.out.println(" ");}
            else{
            System.out.println(" ");
            System.out.println(" TYRE PRESSURE CONDITION IS OK HAVE A SAFE DRIVE!!");
            System.out.println(" ");}
            return d;
                                    }
    // The code A checks the pressure condition of the tyre and decides to refill.
    /* It then gives the driver an instruction to speed to /maintain the operational
    speeds of the compressor. */

public static void main(String[] args){
    System.out.println(" ");
    System.out.println(" SYSTEM REQUIRES YOU TO DRIVE AT " + UZTPIS(120000) + " km/hr ");
    System.out.println(" ");
System.out.println(" MAINTAIN REQUIRED SPEED KM/HR TO RESTORE PRESSURE TO OPTIMUM WHEN IT READS LOW!!!");}
```

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APPENDIX 2: Print out results

```
    DESIRED COMPRESSOR POWER   = 95.61389617284173 WATTS
    @ DRIVE SPEED              = 31 km/hr
    TURBINE POWER              = 65.253888 WATTS
    RATE OF COMPRESSION        = 15.720101931121382 rps
    DESIRED COMPRESSOR POWER   = 95.61389617284173 WATTS
    @ DRIVE SPEED              = 32 km/hr
    TURBINE POWER              = 65.253888 WATTS
    RATE OF COMPRESSION        = 15.720101931121382 rps
    DESIRED COMPRESSOR POWER   = 95.61389617284173 WATTS
    @ DRIVE SPEED              = 33 km/hr
    TURBINE POWER              = 92.91032100000001 WATTS
    RATE OF COMPRESSION        = 17.685114672490727 rps
    DESIRED COMPRESSOR POWER   = 107.56563319432027 WATTS
    @ DRIVE SPEED              = 34 km/hr
    TURBINE POWER              = 92.91032100000001 WATTS
    RATE OF COMPRESSION        = 17.685114672490727 rps
    DESIRED COMPRESSOR POWER   = 107.56563319432027 WATTS
    @ DRIVE SPEED              = 35 km/hr
    TURBINE POWER              = 92.91032100000001 WATTS
    RATE OF COMPRESSION        = 17.685114672490727 rps
    DESIRED COMPRESSOR POWER   = 107.56563319432027 WATTS
    @ DRIVE SPEED              = 36 km/hr
    TURBINE POWER              = 127.44900000000001 WATTS
    RATE OF COMPRESSION        = 19.650127413857884 rps
    DESIRED COMPRESSOR POWER   = 119.5173702157855 WATTS
    @ DRIVE SPEED              = 37 km/hr
TYRE PRESSURE IS LOW!!
THE TYRE NEEDS 120000.0 pascals
TYRE PRESSURE IS LOW!!
```