

Design of an automatic tyre pressure inflation system for small vehicles

Tawanda Mushiri

Department of Mechanical Engineering
University of Johannesburg
P.O Box APK 524
Johannesburg
South Africa

tawandanda.mushiri@gmail.com, tawandamushiri123@hotmail.com

Allan T. Muzhanje

Department of Mechanical Engineering
University of Zimbabwe
P.O Box MP167
Mt Pleasant
Harare
Zimbabwe

allantaku@gmail.com

Charles Mbohwa

Faculty of Engineering and the Built Environment
University of Johannesburg
P.O Box APK 524
Johannesburg
South Africa

cmbohwa@uj.ac.za

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.

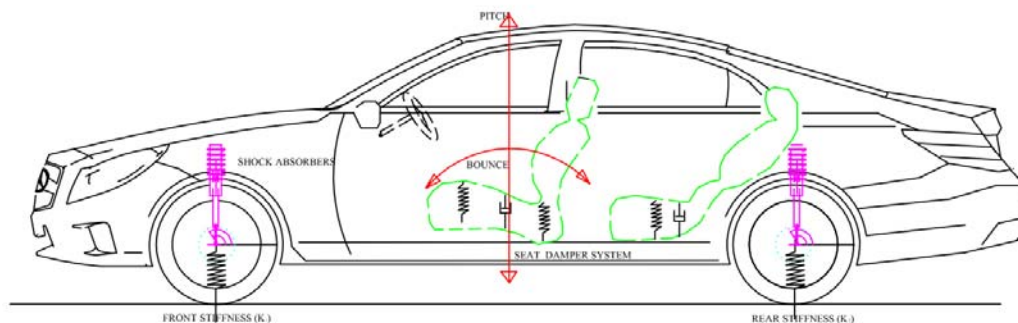


Figure 1. CAD Illustration of the pitch, bounce capability (Singiresu, 2011), p. 539.

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 & Moisesescu, 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 & Moisesescu, 2008).

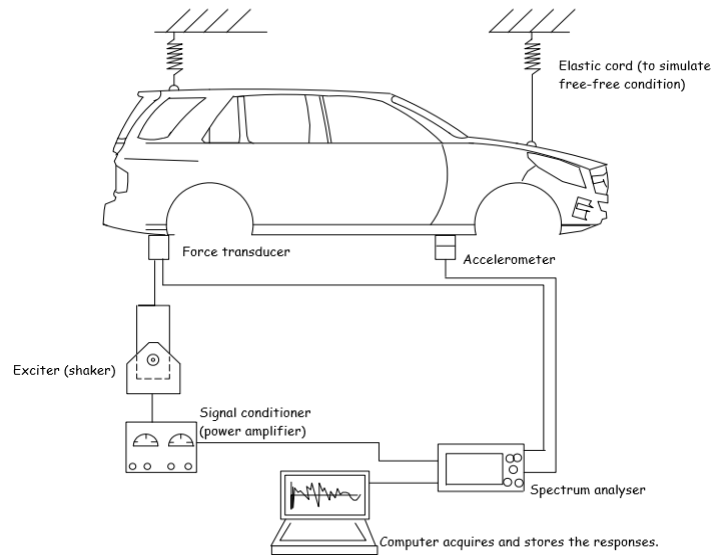


Figure 2. Experimental modal analysis. (Singiresu 2011, p.903.)

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.

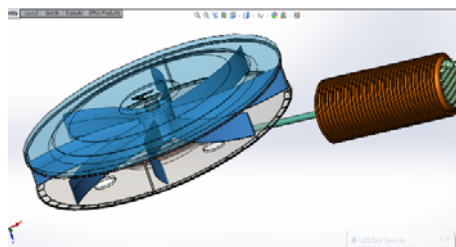


Figure 4. Turbine in place

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 $\Phi 30\text{mm}$ 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.

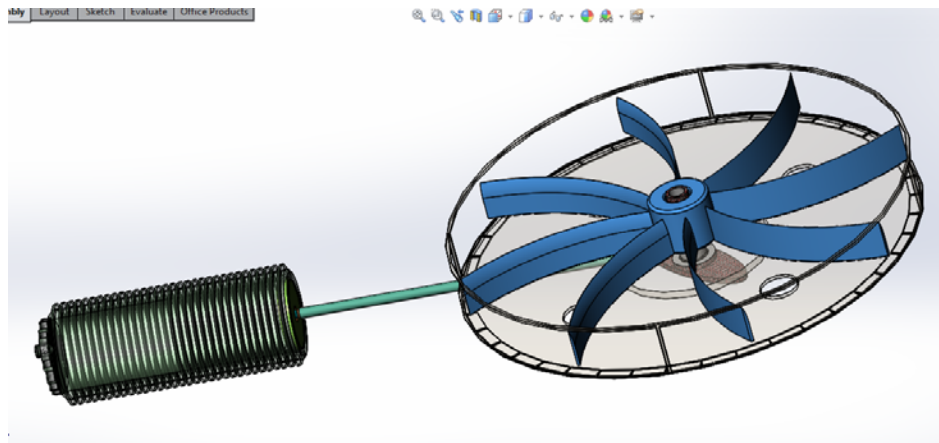


Figure 5. Crank cam at the rear of the turbine unit

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: $V_{\text{wind}} = 25\text{km/hr}$.

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

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:

$$F_d = \frac{1}{2} \cdot \rho \cdot A \cdot C_d \cdot v^2 \quad \text{and thus power in the wind which is}$$

$$P = F_d \times v \text{ becomes } = \frac{1}{2} \cdot \rho \cdot A \cdot C_d \cdot v^3$$

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

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

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:

$$P_{\text{turbine}} = 0.4 \times P_{\text{wind}} = 0.4 \times 125.5 = \underline{50.2 \text{ Watts.}}$$

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.

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

Power of a rotor turbine is given by $P_{\text{rotor}} = \frac{1}{2} \cdot \rho \cdot A_1 \cdot (v_r)^3 = P_{\text{turbine}}$

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

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

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

$$= \underline{29.89 \text{ rps (revolutions per second).}}$$

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:

$$P = T\omega \text{ wherefore } \omega = 2 \pi N \text{ where } N \text{ is in revs/sec}$$

$$T = P/\omega. \text{ Which therefore can be substituted to obtain}$$

$$= (50.2/[2 \times \pi \times 29.89]) = \underline{0.2673 \text{ Nm}}$$

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

Steel C45	Mechanical Characteristics		Parts of Use
	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/m² which is safe driving limit for highways. This translates to 23.6m/s and design temperature

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

$$= 21.91 \text{ i.e. } 273.15 + 21.91 = 295.06\text{K which is comparable.}$$

For the point of support which is at the end of 30mm: Moment $M = 169 \times 0.03 = 5.07 \text{ Nm}$. 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:

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

$D = 0.0080\text{m}$ 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.

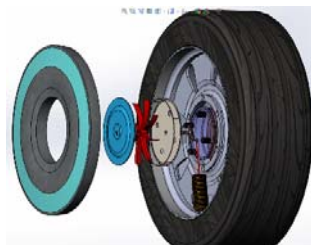


Figure 6. Complete system in operation

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

I would like to thank the team members for the experiments we did and how the research came out successfully. I also thank the Professor, Charles Mbohwa for the continuous support and care. University of Johannesburg is always the pillar of strength for me.

References

1. AATyres, 2015. *Tyre Size Guide*. [Online]
Available at: <https://www.event-tyres.co.uk/tyres/tyre-size-guide>.
[Accessed 11 12 2015].
2. Ajas, M. et al., 2014. Tire Pressure Monitoring and Automatic Air Filling System.. *IJREAT: International Journal of Research in Engineering & Advanced Technology*., 02(02), pp. 1-6.
3. Anghelache, G. & Moisescu, R., 2008. *Analysis of Rubber Elastic Behaviour and its Influence on Modal Properties*, Bucharest: University Polytechnica of Bucharest, 313 Splaiul Independenpei, 060042, Bucharest, Romania.
4. ASHRAE, I., 2005. 2005 ASHRAE Handbook - Fundamentals (IP). *Design conditions for HARARE KUTSAGA AIRPORT, Zimbabwe*, p. 1.
5. Babalas, D. et al., 2015. *Design of a Savonius Wind Turbine*, Xanthi, Greece: Democritus University of Thrace.
6. Beard, J. E. & Sutherland, J. W., 1993. Advances in Design Automation: Robust Suspension System Design.. *ASME*, 1(DE-Vol 65-1), pp. 387-395.
7. Benz, M., 2014. *Mercedes benz photo gallery - G63 -amg- 6x6 suspension*. Stuttgart: Daimler Communications.
8. Benz, M., 2015. *S class S63 - AMG - coupe 008 - MCFO*, Stuttgart: Daimler Communications.
9. BMW, 2008. *BMW Runflat Technology*. [Online]
Available at: <http://www.bmwrunflat-technology@youtube.com>
[Accessed 5 December 2015].
10. Bowhil, I., 2013. *Automatic Tyre Inflation System (ATIS) - cement and lime*. London: Larfage Tarmac.
11. Brodbeck, S., 2013. *Precision Inflation Showcase: Agritechnica 2013*. Canada: PTG Tyre Inflation Systems.
12. CODA, D. s., 2013. *SIT - Self Inflatng Tire Technology*. [Online]
Available at: <http://www.selfinflatingtire.com/>
[Accessed 29 December 2015].

13. Continental, A., 2008. *Tire Basics: Passenger Car Tyres..* [Online]
Available at: www.continental-tyres.com
[Accessed 23 12 2015].
14. Daimler, A., 2015. *Central Tyre Inflation System: Mercedes-Benz military vehicles.* [Online]
Available at: <http://www.mercedes-benz.com/military-vehicles>
[Accessed 21 September 2015].
15. Divisions, D. C. V. S., 2010. *Central Tire Inflation System- Troubleshooting Guide*, Ohio: Spicer CTIS, Ohio USA.
16. Douglas, J., Gasiorek, J., Swaffield, J. & Jack, L., 2005. *Fluid Mechanics*. 5th ed. London: Pearson Prentice Hall.
17. Dr. Benedict, R., 2012. *A System for Automatically Maintaining Pressure in a Commercial Truck Tire*. Ohio: The Goodyear Tire and Rubber Company.
18. Hannah, J. & Stephens, R., 1970. *Mechanics of Machines: Elementary theory and examples..* 3rd ed. London: Edward Arnold (Publishers) Ltd..
19. Hurst, K., 1999. Concept Selection. In: *Engineering Design Principles*. New York: John Wiley and Sons, pp. 53-63.
20. Infiniti, 2015. *Tyre Pressure Maintenance System: Inspired Performance.* [Sound Recording] (InfinitiUSA.com).
21. Johnson, C., 2013. *Advanced Tyre Pressure Monitoring System.* [Online]
Available at: www.johnsoncontrols-advanced-tyre-pressure-monitoring-system@youtube.com
[Accessed 15 November 2015].
22. Junankar, H., Bihare, V., Giradkar, N. & Gupta, C., 2015. A Review: Automatic Tyre Inflation System.. *International Journal for Scientific Research and Development (IJSRD)*., 03(01), pp. 118-120.
23. Khurmi, R. & Gupta, J., 2005. *A textbook of Machine Design: (1st multicolour edition)..* 14th ed. New Delhi: Eurasia Publishing House (Pvt.) Ltd..
24. Kottayam, K., 2002-2003. *Dynamics of Machinery..* 1st ed. India: Mahatma Gandhi University.
25. Kubba, A. & Jiang, K., 2014. A Comprehensive Study on Technologies of Tyre Monitoring Systems and Possible Solutions.. *Open Access: sensors*, 11 June, 1(14), pp. 10306-10345.
26. Kurt, E., 2012. *MotorAuthority: The Luxury and Performance leader..* [Online]
Available at: <http://www.motorauthority.com>
[Accessed 23 September 2015].
27. Lee, C.-R. et al., 2012. *Validation of FEA Tire model for Vehicle Real Time*, London: Engineering Technology Associates, Inc..
28. Ling, A. L. & Mulyandasari, V., 2011. *Compressor Selection and Sizing (Engineering Design Guideline).* [Online]
Available at: <http://www.klmtechgroup.com>
[Accessed 28 04 2016].
29. Mohapatra, A., 2011. Design and Implementation of Diaphragm Tyre Pressure Sensor in a Direct Tyre Pressure Monitoring System (TPMS) for Automotive Safety Applications.. *International Journal of Engineering Science and Technology*, August, 3(8), pp. 6514-6524.
30. Muvuringi, M. P., 2012. *Road Traffic Accidents in Zimbabwe, Influencing factors Impact and Strategies..* Amsterdam: KIT (Royal Tropical Institute).
31. NACFE, 2013. *Report Conducted by the North American Council for Freight Efficiency on the Confidence of adopting Tire Pressure Systems..* North America: North American Council for Freight Efficiency.
32. NACFE, 2013. *Report Conducted by the North American Council for Freight Efficiency on the Confidence of Adopting Tire Pressure Systems..* North America: North American Council for Freight Efficiency.
33. *National Geographic Documentary-Bugatti Super Car..* 2014. [Film] Directed by Dylan. Weiss. United States of America.: Cry Havoc Productions..
34. Omprakash, P. & Kumar, S., 2014. M.A.R.S Mechanized Air Refilling System. *International Journal of Information Sciences and Techniques (IJIST)*, May, 4(3), pp. 91-98.
35. Pletts, T., 2006. *A Literature Overview of Central Tyre Inflation Systems..* Pietermaritzburg: University of KwaZulu - Natal..

36. Ragheb, M., 2014. *Wind Energy Conversion Theory, Bertz Equation..* [Online] Available at: <http://www.Wind Energy Conversion Bertz Equation.com> [Accessed 01 05 2016].
37. Randall, R. B., 2011. *Vibration Based Condition Monitoring*. 1st ed. South Wales, Australia: John Wiley and Sons.
38. Sachin, J. M., Varghese, S. T., Vijayan, V. & Yedukrishnan, G., 2014. Tyre Pressure Inflation System. *International Journal for Research and Development in Technology*, 1 May, 1(1), pp. 1-20.
39. Schuler, B., 2010. *PTG Professional Tyre Inflation Systems made in Germany..* [Online] Available at: <http://www.military-mobility.eu/bernhard.schuler@ptg.info> [Accessed 20 September 2015].
40. Singiresu, S. R., 2011. *Mechanical Vibrations*. 5th ed. Upper Saddle River: Prentice Hall.
41. Thorat, S., 2015. *Seminar On Self inflating tyre: Mechanical ENgineering World..* [Online] Available at: <http://www.mechengg.net/2015/03/seminar-on-self-inflating-tyres.html> [Accessed 29 December 2015].
42. TMC S.2 Tire and Wheel., S., 2010. *TMC S.2 Tire & Wheel Study Group Information report. 2010-2*, Arlington: TMC/ATA.
43. *Top Gear*. 2014. [Film] Directed by Andy Wilman. United Kingdom: BBC.
44. van Zyl, S., 2013. *Study on Tyre Pressure Monitoring Systems(TPMS) as a means to reduce Light Commercial and Heavy-Duty Vehicles fuel consumption and CO2 emmissions..*, Delft: TNO.
45. Varghese, A., 2013. *Influence of Tyre Inflation Pressure on Fuel Consumption, Vehicle Handling and Ride Quality..* Goteborg, Sweden: Chalmers University of Technology.
46. Wang, S.-l., Liao, W.-X. & Peng, S.-C., 2002. *Introduction of the Tire Pressure Detection/Adjustment System*, Taiwan: Dept of Mechanical Eng. Nanya Institute Technology.

Biography

Tawanda Mushiri is a PhD student at the University of Johannesburg in the field of fuzzy logic systems and maintenance, is a Lecturer at the University of Zimbabwe teaching Machine Dynamics, Solid Mechanics and Machine Design. His research activities and interests are in Artificial intelligence, Automation, Design and Maintenance engineering Contacted at tawanda.mushiri@gmail.com / 201337963@student.uj.ac.za

Allan T. Muzhanje is a Mechanical Engineering student at the University of Zimbabwe (2016). Contacted at allantaku@gmail.com

Charles Mbohwa is currently a Full Professor of Sustainability Engineering and Engineering Management at the University of Johannesburg, South Africa. Contacted at cmbohwa@uj.ac.za

[APPENDICES](#)

[APPENDIX 1. Java android code](#)

```

File: C:\Users\alantaku\JAVA\Project\android\app\UZtps.java
1 import java.util.Scanner;
2
3 class UZtps{
4
5 static double P_turbine(int Speedcar,double Pintake){
6
7 /* Speed of car = speed of the wind thus power in wind
8 can be obtained by the method below */
9 double mps = ((Speedcar*km/hr*/1000)/(60*60));
10 double Pwind = 0.5*1.225*1.7*0.36*Math.pow(mps,3);
11 double P_turbine = Pwind*0.4*0.85;
12 // Power delivered by the Turbine to the Compressor
13 unit.
14 double p = P_turbine/(0.5*1.225*0.021642431);
15 double v = Math.pow(p,(0.33333333333));
16 double N1 = v/(0.083*Math.PI*2);
17 double N2 = N1*(0.040/0.083);
18 // The crank speed of the Compressor unit.
19 double Vc = 6.36173*Math.pow(10,-07);
20 double V1 = 5.71848*Math.pow(10,-05);
21 double m = (264000/Pintake);
22 double V4 = Vc*Math.pow(m,0.769230769);
23 double V4 = V1-V4;
24 double Pcompressor = 4.333333333*Pintake*V4*(Math
25 .pow(m,0.23076923))-1)*N2;
26 // The power required by the Compressor to achieve
27 compressor of pressure to deliver 264000 pascals.
28 double SPEED = 85;
29 if((Speedcar < 85) && (P_turbine < Pcompressor)){
30
31 while(P_turbine < Pcompressor){
32 mps = ((Speedcar*km/hr*/1000)/(60*60));
33 Pwind = 0.5*1.225*1.7*0.36*Math.pow(mps,3);
34 P_turbine = Pwind*0.4*0.85;
35 // Power delivered by the Turbine to the Compressor
36 unit.
37 p = P_turbine/(0.5*1.225*0.021642431);
38 v = Math.pow(p,(0.33333333333));
39 N1 = v/(0.083*Math.PI*2);
40 N2 = N1*(0.040/0.083);
41 // The crank speed of the Compressor unit.
42 Vc = 6.36173*Math.pow(10,-07);
43 V1 = 5.71848*Math.pow(10,-05);
44 m = (264000/Pintake);
45 V4 = Vc*Math.pow(m,0.769230769);
46
47 Va = V1-V4;
48 Pcompressor = 4.333333333*Pintake*V4*(Math
49 .pow(m,0.23076923))-1)*N2;
50 // The power required by the Compressor to achieve
51 compressor of pressure to deliver 264000 pascals.
52 Speedcar++;
53 System.out.println(" ");
54 System.out.println(" TURBINE POWER
55 = " + P_turbine + " WATTS ");
56 System.out.println(" RATE OF COMPRESSION
57 = " + N2 + " rps ");
58 System.out.println(" DESIRED COMPRESSOR
59 POWER = " + Pcompressor + " WATTS ");
60 System.out.println(" @ DRIVE SPEED
61 = " + Speedcar + " km/hr ");
62
63 SPEED = Speedcar++;
64 System.out.println(" ");
65
66 else if((Speedcar < 85) && (P_turbine > Pcompressor)){
67 System.out.println(" SLOWDOWN TO INITIATE SAFE
68 COMPRESSOR TO ATLEAST " + SPEED + " km/hr ");
69
70 return SPEED;
71
72 public static void main(String[] args){
73 System.out.println(" ");
74
75 }
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
2210
2211
2212
2213
2214
2215
2216
2217
2218
2219
2220
2221
2222
2223
2224
2225
2226
2227
2228
2229
2230
2231
2232
2233
2234
2235
2236
2237
2238
2239
2240
2241
2242
2243
2244
2245
2246
2247
2248
2249
2250
2251
2252
2253
2254
2255
2256
2257
2258
2259
2260
2261
2262
2263
2264
2265
2266
2267
2268
2269
2270
2271
2272
2273
2274
2275
2276
2277
2278
2279
2280
2281
2282
2283
2284
2285
2286
2287
2288
2289
2290
2291
2292
2293
2294
2295
2296
2297
2298
2299
2300
2301
2302
2303
2304
2305
2306
2307
2308
2309
2310
2311
2312
2313
2314
2315
2316
2317
2318
2319
2320
2321
2322
2323
2324
2325
2326
2327
2328
2329
2330
2331
2332
2333
2334
2335
2336
2337
2338
2339
2340
2341
2342
2343
2344
2345
2346
2347
2348
2349
2350
2351
2352
2353
2354
2355
2356
2357
2358
2359
2360
2361
2362
2363
2364
2365
2366
2367
2368
2369
2370
2371
2372
2373
2374
2375
2376
2377
2378
2379
2380
2381
2382
2383
2384
2385
2386
2387
2388
2389
2390
2391
2392
2393
2394
2395
2396
2397
2398
2399
2400
2401
2402
2403
2404
2405
2406
2407
2408
2409
2410
2411
2412
2413
2414
2415
2416
2417
2418
2419
2420
2421
2422
2423
2424
2425
2426
2427
2428
2429
2430
2431
2432
2433
2434
2435
2436
2437
2438
2439
2440
2441
2442
2443
2444
2445
2446
2447
2448
2449
2450
2451
2452
2453
2454
2455
2456
2457
2458
2459
2460
2461
2462
2463
2464
2465
2466
2467
2468
2469
2470
2471
2472
2473
2474
2475
2476
2477
2478
2479
2480
2481
2482
2483
2484
2485
2486
24
```