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Design Of A Novel Pressure Replenishing System To Sustain Automobile Tyre Pressure Without Human Intervention

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Abstract

Automobile Tyres are silent killers! No matter how well they are taken care, how good and expensive they are, they still leak-out 10-15 kPa of pressure every month, and this is equivalent of adding an unnecessary load of 70kg into the car. Properly maintained tyre pressure is known as one of the most essential factor for safe and economical motoring. The air from inside the tyre chamber normally escapes naturally through the tyre wall which is more permeable causing the tyre pressure to drop. Tyres which run below safe operating pressure value often lead to major road accidents due to catastrophic failure of these tyres. Most non-commercial vehicles are often continuously used with improper tyre pressure due to lack of awareness how much it is dangerous. Besidesbeing hassle to frequently checkand inflate the tyres manually, the malfunction of the air supply kiosks has also been the reason not to inflate frequently. Therefore, this paper presents of how the issue has been tackled and towards the end proposes a complete solution design of how a novel approach could sustain the tyre pressure without human intervention. Thus, not only the time and hassle to inflate could be overcome, but it reduces the risk of fatal accidents due to tyre explosion and save lives at large.

Keywords: tyre inflating system, tyre pressure sustaining system, tyre pressure monitoring system, automatic tyre inflating system, automatic inflatable tyre, automotive tyre

INTRODUCTION

Often automobile tyre experience wear on the outer tread area which is mainly caused by vehicles running with under inflated tyres. When a tyre runs in underinflated condition, there would be too much of contact area with the road by the outer treads due to its profile and this causes pre-mature wear-off [1]. Underinflated tyre with too little air pressurewould also seriously build excessive heat which could cause a sudden tyre failure that could lead to catastrophic event [2].Technology & Maintenance Council of the American Trucking Associations [3] claims that, a tyre running with 20% underinflated condition would experience the losing30% of its life due to its extreme-hot region operational condition. On the other hand, defects on a tyre, such as tread separation would seriously cause a blowout as shown in Figure 1, which would eventually bring the driver to the uncontrolled limit over the vehicle[4]. The main reason for this phenomenon is tyres running with underinflated condition where, the build-up temperature causes separation of tyre layers and tear them into pieces.

Figure 1Sample of tyre blowout due to tread separation

Knowing the consequences of running vehicles with improperly inflated tyres, the government of the United States finally came out with the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) act of 2000 which mandates all new vehicles equipped with Tyre Pressure Monitoring System (TPMS). This system alerts the user when the tyre pressure drops 25% - 30% of the original pressure supposed to be. It is proven that with this Act, the US government insists awareness among vehicle users about the importance of proper tyre inflation [5].

Properly maintained tyre pressure also greatly improve vehicle fuel efficiency as compared to vehicle running with underinflated tyre. Ina full-vehicle simulation model developed by [6]for the New European Driving Cycle (NEDC city cycle), fuel consumption reduction up to 5 % was observed simply by increasing the tyre pressures from 2 to 3 bar. Tyre Industry Council in the UK have highlighted that, very little attention is given to tyre pressure by vehicle owners through their road survey where, over 1000 tyres, only 5% were inflated to correct pressure, while 72% were under inflated and the remaining over inflated their running tyres [7].

Visual methods or the kicking or thumping of the tyres to inspect underinflated tyres are not suitable to know the correct tyre pressure. Some tyres always look underinflated, some even have stiff sidewalls and normally look inflated. Differences in tyre inflation cannot be easily identified unless reliable pressure gauge is used[9]. Therefore, all the new series of BMW automobiles have been fitted with tyre pressure control system (RDC) which electronically monitors tyre pressure at all four wheels by means of sensors as of March 2014 [8].

Many solutions have been designed in the past to automatically inflate tyres when deflation occurs and each solution has its own advantages, disadvantages and limitations. The intention of this research is to provide a better solution to comply with the objectives so as to create a cheaper/cost effective solution without any major modification towards automotive tyres for medium level users. Through the series of concept, evaluation, and final concept selection, the desired system was design and analysed to suit actual static and dynamic running condition of a vehicle. The system was engineered based on Proton Perdana, which is an executive care produced by Malaysia (National) automotive industry. The solution comprises high pressure capsule to replenish air into the tyre when deflation occurs and this is controlled by a mechanically controlledmicro valve system which is called pressure compensating system (PCS).It is a complex air controlling system where the automatic replenishing has to take place through the same inflating valve without any modification done onto it. The critical review of prior technology reveals that there are two main types where, thepressurized air supply comes from a centralized system and decentralized type where pressurized air supply system embedded to each wheel. Centralized type requires an intact dynamic air transfer connections to channel the air supply from stationary section to rotatable section of the vehicle. Clearer example of this technology can be seen in a design called Central Tyre Inflation System (CTIS) developed by [10]. This technology is seen to be suitable only for vehicle equipped with air braking system because the pressurized air supply comes from the air braking reservoir system which is not available in a normal passenger vehicle. Inspired by CTIS, an improved version of CTIS technology called Centralized Compressor System (CCS) has been developed with the aim to adapt CTIS technology into normal passenger vehicle. Since normal passenger vehicle doesn’t have air braking system, an air compressor has been added to CCS which act as pressurized air supply system [11]. The system schematic of CCS technology is shown in Figure 2.

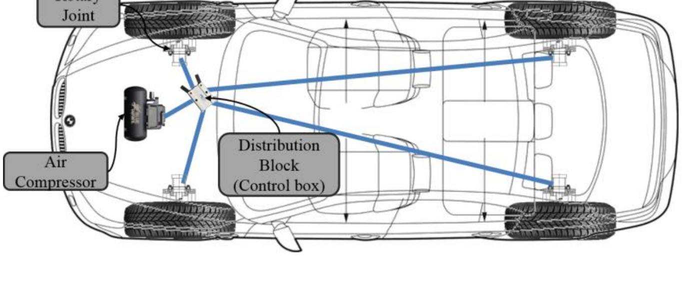

Figure 2Schematic of Centralized Compressor System (CCS)

CCS design comprises of a 12 VDC air compressor, distribution block, microprocessor, solenoid valve, relay and rotary joint. It has a built-in electronic control that uses pressure monitoring system to trigger upon start up and checks tyre pressure. Pressure monitoring system sends the required pressure data via a microprocessor, and later it then signals the distribution block to supply air to the tyre. Distribution block is attached to compressor and controlled by solenoid valves for precise air distribution.The main drawback of this system is, the wear and tear of the rotary join which requires frequent maintenance activity to avoid air leakage from the system which leads into significant efficiency drop.

Alternately, the decentralized type can be described as independent inflating system which has its own individual air control and pressurized air supply system. The whole system is fully embedded to the wheel of the vehicle and it doesn’t requires rotary joint to channel the air from any stationary section of the vehicle, where the pressurized air is supplied from within the system itself. The sample of this technology is electromagnetic pump inflation system as shown in Figure 3, and this system requires individual pumps due to the nature of its decentralized system [12]

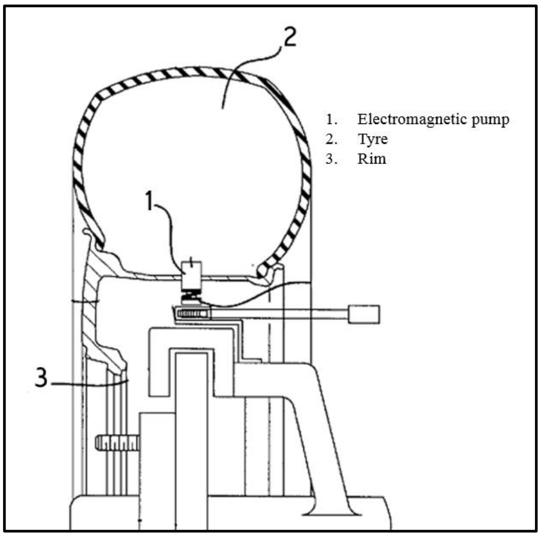

Figure 3 Electronic pump inflating system

Also, this very much mechanical approach requires the redesign of the wheel rim which is not practical. Most invention of decentralized type requires major changes to the rim design which ends to be a not practical and not economical solution and these drawback holds the system from being developed to date.

Therefore, considering all available solutions, either in use or not, this paper presents a new design of decentralized type pre-equip the compensation system with pressure capsule acting as reservoir to supply pressurized air for a longer period of time (12 months or a year). It was intended to re-inflate tyre back to its pre-set value automatically via mechanically controlled compensation system.Considering its significant practicability, no changes are required towards the vehicle since the device is standalone and detachable from the wheel as easy as removing a wheel. The primary aim of this solution was to sustain tyre's safe operating pressure without having to inflate the tyres for up to a year. Thus, the owner needs to be least bothered to check nor manually re-inflate the tyre for a year, which practically has to inflate every two weeks without this system. Every time the pressure drops 2% - 3%, the capsule would automatically replenish the amount of loss air into the tyre enabling the pressure inside the tyre is always sustained. The capsule was designed based on the established mathematical model correlating amount of daily air loss every day and its relative pressure drop. Thus, the re-inflation would be done automatically via compensation system and this will ensure proper tyre pressure being filled in accordingly at all time. When the capsule pressure itself drops below the supply pressure, an indicator would change to red, signalling the user to inflate the chamber and normally this happens only once a year.

DESIGN METHODOLOGY

Critical design development stages have been carried out to materialize PRE-REP conceptual design. The aim was to create a device which is capable to cater compensation up to 12 months and in order to achieve that, the pressure capsule must have enough storage of pressurized air to sustain the system throughout the said time interval. The developmental stages started with preliminary investigation stage which mainly investigates the constraint data for desired specification setting. In preliminary investigation stage, the amount of pressure requires to be inflated has been identified accordingly and by using the same pressure value as maximum working pressure, further analysis has been done to further analyse pressure capsule strength capability. Next step was to conceptualize the design stage where,the device concept and system layout creation took place. It was divided into three main sections as follow:

1. Compensation system design
2. Pressure capsule design
3. Overall system integration

All three sections were performed concurrently as reflected in Figure 4 Final outcome was the finalised version of PRE-REP conceptual design.

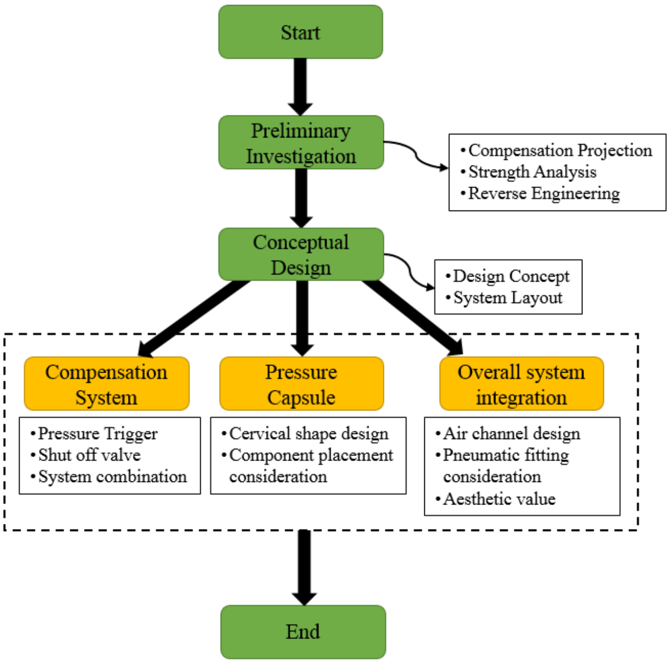

Figure 4Design development methodology flowchart

PRELIMINARY INVESTIGATION

In previous research, a mathematical model has been developed to estimate the amount of pressurized air inflated into the capsule to sustain the device for a year. The tyre pressure pre-set value was 228 kPa but in order to enable smooth air transfer, pressure capsule must have higher pressure than tyre pressure pre-set value and therefore, it was decided that the pressure capsule must contained at least 290 kPa of pressurized air. Based on the graph in Figure 5, it clearly indicates that 8449 kPa is required to cater compensation demand for a year period under dynamic condition. This value is also the maximum working pressure for the pressure capsule. Pressure capsule is required to contain the maximum working pressure of 8449 kPa without fail. Structural simulation analysis has been performed towards the pressure capsule design using the said maximum working pressure value to evaluate its safe operational strength.

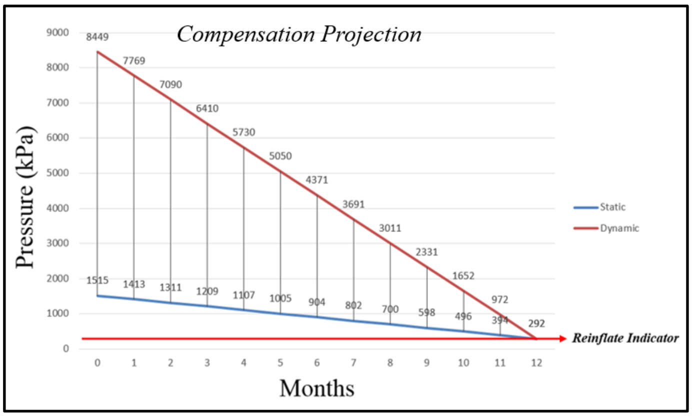

Figure 5 Compensation projection chart established via mathematical model

To ensure the device is fully embedded into the wheel, accurate information of the wheel and hub profile in terms of 3D data, a 3D FAROARM scanner has been used for scanning and reverse engineer theprofile. Scanning involves wheel hub assembly and rim since the device is intended to be fitted between wheel hub and rim assembly. Figure 6 shows related parts involves were covered with a special white powder to improve scanning responses.

a. Hub profiling b. Rim profiling

Figure 6Profile scanning setup for a.Hub profiling, and b. Rim profiling

The pressure capsule was required to be fitted within wheel assembly and collision between neighbouring parts of the wheel assembly during wheel rotation must be critically considered to avoid collision andmechanical contact at any rotational speed. Once the pressure capsule prototype has been validated, it was then been used as design reference for the compensation system. Since it has to be built inside the pressure capsule, the housing of the compensation system must adapt the cervical shape of pressure capsule and this has been taken into a serious consideration.

Using the scanning setup, scanning process was done towards critical area to identify possible mounting and fitting design for the device to be fully embedded into the wheel assembly. Sample of 3D data can be seen in Figure 7 where, only a small portion of rim profile has been scanned since the revolving profile shape is uniform. Based on the 3D data obtained, 3D shape of the rim profile as shown in Figure 8 was generated and used as design input.

Figure 7 3D Datasample

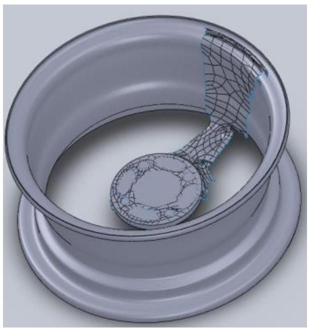

Figure 8 Generated profile sample

Preliminary concept of PRE-REP intended to embed the compensation system within the pressure capsule and it is essential to create a pre-prototype unit of the pressure capsule design for fitting validation test before further development towards the compensation system is carried out. Figure 9 shows the pressure capsule design without compensation system attachment.

Figure 10 shows FEA analysis results of the pressure capsule after undergone structural simulation analysis using pre-determined maximum working pressure of

8449kPa. The material used for the simulation was AISI 304 Stainless Steel. By using von misses stress model, the maximum von misses stress value for the analysis on the capsule is 1.717×10^{8} Pascal where the material yield strength 2.068×10^{8}Pascal so the factor of safety of the capsule was 1.2 which is considered safe according to ASME pressure vessel code. The results indicate that the pressure capsule design structure theoretically manageto contain the maximum working pressure without fail. Based on finite element analysis (FEA) the AISI 304 Stainless steel has been chosen as the pressure capsule material.

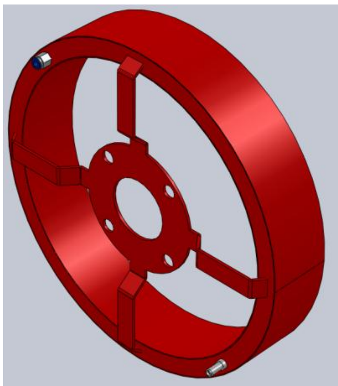

Figure 9 Pressure capsule design for strength analysis

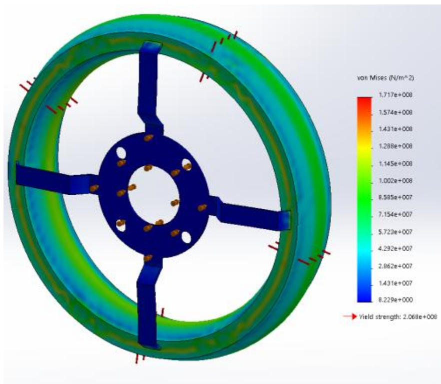

Figure 10 Pressure capsule FEA analysis result

CONCEPTUAL DESIGN

PRE-REP comprises of pressure capsule which provided pressurized air supply for the system. Compensation system itself consist of two sub-system and they are pressure trigger system and shut off valve system. Compensation system will automatically supply appropriate amount of pressurized air to compensate the pressure losses.

Pressure trigger receives pressure feedback from the tyre and whenever the tyre pressure drops below pre-set value, the system will trigger shut off valve system to open up the supply channel. Once the compensation process completed to compensate pressure losses from the tyre, the pressure trigger will automatically trigger the shut off valve system to close the supply channel.

Figure **11** shows overall system layout of the device.

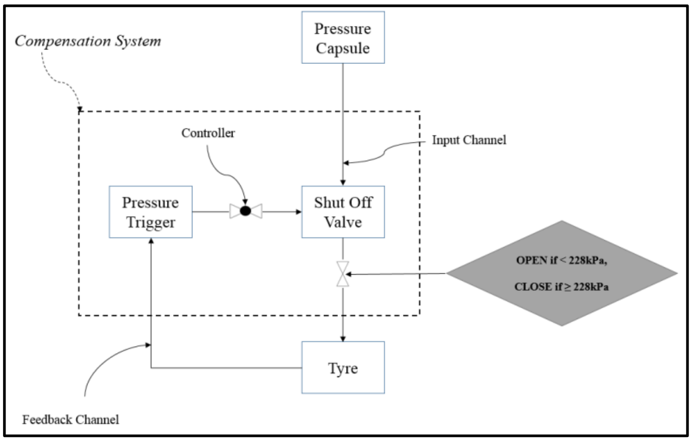

Figure 11Schematic diagram of compensation system design

Based on the critical conceptual design, the compensation system must be built inside the pressure capsule and this requires a lot considerations of constraint towards the design of compensation system. Figure 12 shows the conceptual system integration between compensation system and pressure capsule.

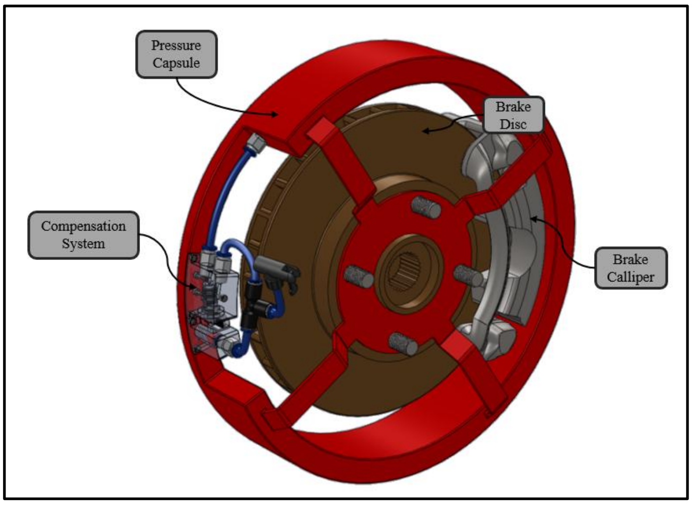

Figure 12 Conceptual system integration between pressure capsule and compensation system

PRE-REP system is a fully mechanical based system, not even a single electrical component involved. This is essential to keep the system simplified and optimized to ensure it is cost effective and highly reliable. Combination of those two sub-system (pressure trigger and shut off valve) has successfully formed to the development of compensation system of the device. Those two sub-system are attached to pressure capsule enabled the final assembly of the device. The device will then be assembled together with the wheel of the vehicle.

Figure **13** shows design concept of the said device which was based on [13] conceptual design.

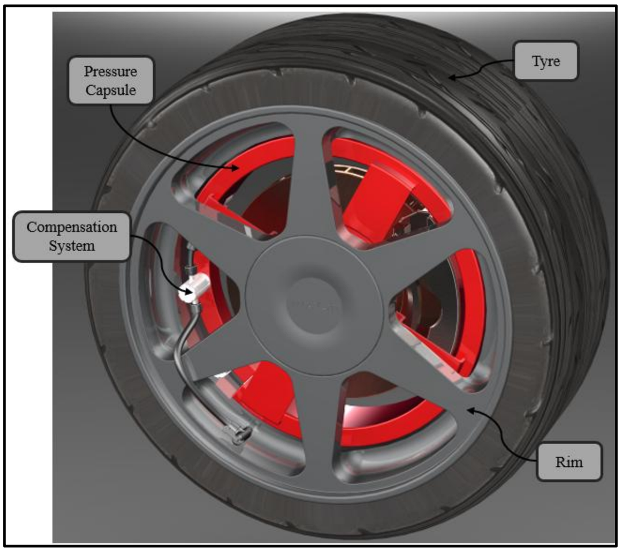

Figure 13PRE-REP conceptual design

CONCLUSION

Based on the final outcome of the conceptual design, PRE-REP is expected tomaintain proper tyre pressure at all time with the compensation feature it has for the period of a year or more. With the completion of the conceptual design, future development of the actual prototype can be done using all references and design being created. The aim to have a fully embedded design of the device (PRE-REP) into the wheel assembly has been fulfilled accordingly. It is expected that, the actual prototype is to be developed in near future of this year which can be a solution to savelives.

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