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Developing an Automatic Tire Pressure Control System To Improve the Tractive Efficiency of Tractors

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Abstract: In this research it is aimed to develop an automatic tire pressure control system for slippage control in order to improve the tractive efficiency of tractors. The developed system was designed in a flexible structure which can be adapted to all brand and model of tractors. With the automatic tire pressure control system, it is aimed to increase the efficiency of drawbars, to reduce fuel consumption and to bottom out negative traffic effects which will occur on the field.
The system consists of electronic control unit, pneumatic control unit, user interface, central control unit and auxiliary units. Evaluating slippage data which electronic control unit gets from each drive tire with the help of developed software; it is aimed to make slippage stay in indicated limit by decreasing and increasing tire pressure. Working with tire pressure control sensors and pneumatic unit integratedly, software speed sensors provided pressure control.
In this article, it is aimed to give design and production stages of the system, which is a part of the research, and measurement carried out under the laboratory conditions. In the second stage of the research, the system will be tested in field conditions.
Key words: Drawbar strength, tire pressure, field traffic, pressure control, slippage

INTRODUCTION

One of the main purposes of agricultural production activities is to increase efficiency by reducing inputs. The biggest input of the field activities is created by tractor operations. The aims of automatic tire pressure control system to be developed with this project are to improve tractive efficiency, reduce fuel consumption and adverse traffic impacts to the lowest level that would occur in the soil. In field conditions, working of the tractor with more than 10% slppage increases losses and leads to excessive power consumption. The economic life of the tractor also reduces. As a result of the Transportation Recall Enhancement, Accountability and Documentation Act (TREAD Act) all light vehicles sold in the United States must be equipped with a Tire Pressure Monitoring System (TPMS) as of September 1st, 2007 (SAE, 2008).

According to Serrano et al. (2009) the use of higher tyre inflation pressures, showed a slight reduction (3%–5%) in work-rate and a large increase in fuel consumption per hectare (10%–25%), even in good traction conditions, shown by the interval of slip values (7%–15%). In these dry farming soils the above practises should be questioned.

None of the tractors used in agricultural production activities in Turkey is equipped with an automatic tire pressure control system. With increasing use of the system which will be produced in the project, the above-mentioned disadvantages will be eliminated and it will contribute to the country economy.

A TPMS consists of a wireless Tire Pressure Sensor (TPS) module inside each tire and a single receiver in the car (Roundy, 2008). Most so-called direct TPM systems consist of a Sensor/ASIC IC, LF interface, RF transmitter, antenna and a primary battery as power source (Fischer 2003; Hackl 2006; Löhndorf 2007).

Lee et al. (2008) has developed a system which measures tire pressure and transmits it to the pressure control unit via radio frequency and adjusts tire pressure automatically with this transmitted information (Active Tire Pressure Control System, ATPCS). By the help of this system, they have achieved success at the rate of %80 in the study carried out under the laboratory conditions.

Some ideas that have been tried are monitoring the vibration of the wheels (Craighead, 1997), image processing to monitor the tyre tread (Chen et al., 1993), using eddy currents to monitor delamination of the tyre (Gros, 1997) or monitoring tyre pressure directly (Hill et al.,1992). According to Cullen et al. (2002) the problems with these approaches are that they each have some major flaws.

The system developed in the research increases the drawbar strength by decreasing human factors to a minimum level and it also decreases soil compaction emerging from excessive pressure on soil by creating working opportunity wih the most appropriate tire pressure. Besides, reducing fuel consumption, the system provides economical contribution.

MATERIALS and METHOD

The system evaluate each drive tire slippage data and increases or decreases the tire pressure to keep slippage within the specified limits. The system consists of the slippage control unit, the tire pressure sensor and a developed software which controls the pressure with a central control unit.

The working ways of the tractors with different agricultural devices and machines were determined and the system was designed according to this. In the study, the tests of pneumatic control unit were put into practice under laboratory conditions. Moreover, the tests without equipment on straight road were carried out and later on, evaluating the results, improvement works were done. Evaluating slippage data got from each drive tire in field mode, the system made slippage stay in determined limit by means of decreasing and increasing tire pressure. Working with speed sensors, sensors checking tire pressure and pneumatic unit on it integratedly, the system provided pressure control with a developed software.

The units designed in the department of mechatronics design were mentioned under two main titles as electronic and mechanical design.

Mechanical Design: 3D modellings of the system were done according the capacity calculations having been done and the standard parts having been chosen.

Electronic Design: The algorithm writing was completed according to the working principle of the system in electronic design. As the control of the system wasn't possible with standard cards and controllers, the appropriate card designs were produced by the help of Altium electronic card designing programme. As a result of the difficulties occuring in placing of pressure sensors, a wireless connection between electronic control unit and pressure sensors was made.

The designed tire pressure control system is seen in Figure 1. There are speed and pressure sensors on each tire. The data got from these sensors are sent to central control unit via wireless connection.

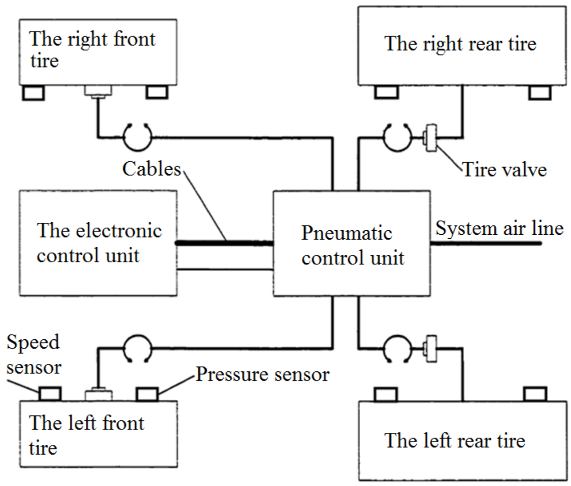

Figure 1. Schematic representation of the tire pressure control system

The calculation of the required air capacity amount for the system;

The air capacity amount of the compressor was determined with the formula below.

$$V_a = V_t.\frac{P_{max}-P_{min}}{P_a} \quad (1)$$

In this formula;

Va: The required compressor volume for inflating all the tires

Vt: The total tire volume

Pmax: The maximum pressure of the tires (23 psi)

Pmin: The minimum pressure of the tires (14 psi)

Pa: The pressure of atmosphere (14.69 psi)

The total tire volume is 1554 liter, rear tires (2x527 l) and front tires (2x250 l).

The required air capacity of the compressor for inflating all the tires depending on the values above is 952 l.

The compressor speed was found by the help of the formula below;

$$n_{kr} = \frac{n_{mr}\ x\ d_f}{d_k} \qquad (2)$$

In this formula;

n_{kr} : the compressor speed at idling speed (min^{-1})

n_{mr}: the idling speed of the engine (800 min^{-1})

d_f: the caliber of fan pulley (135 mm)

d_k: the pulley caliber of the compressor (110 mm)

By the help of the values above, the compressor speed in a condition that the engine works at idling speed was found out as n_{kr}=981min^{-1}.

The compressor speed in the circumstances (n_{mt}=1800 d/d) that the engine works under field conditions was found out as n_{kt}=2209 min^{-1}.

The air amount which the compressor will pump in one minute under the field conditions;

$$v_{kd} = n_{kt}.v_k \quad (3)$$

In this formula;

vk: The air amount which the compressor pumps at one revolution (0.11 l/rev)

The duration to inflate all the tires from minimum air pressure (14 psi) to maximum air pressure (23 psi)

$$t_t = \frac{V_t}{v_{kd}.\eta_k} \qquad (4)$$

In this formula;

η_k : The performance of the compressor

The 2 psi inflation time for one of the front tires;

$$t_ö = \left(\frac{2.V_ö}{14.69}\right) / \left(v_{kd}.\eta_k\right) \qquad (5)$$

This duration was found out as tö=12 s in test measurements.

The 2 psi inflation time for one of the rear tires;

$$t_a = \left(\frac{2.V_a}{14.69}\right) / \left(v_{kd}.\eta_k\right) \qquad (6)$$

In the test measurements carried out, ta=21 was found out.

The selection and the placement of the compressor

The compressor having 110 cc stroke capacity was connected to the air tube having the capacity of 15 liter and the pressure of 116 PSI with an air pipe placed on the engine and having 2 valves on. The compressor gets its movement from the fan with belt and pulley system (Figure 2).

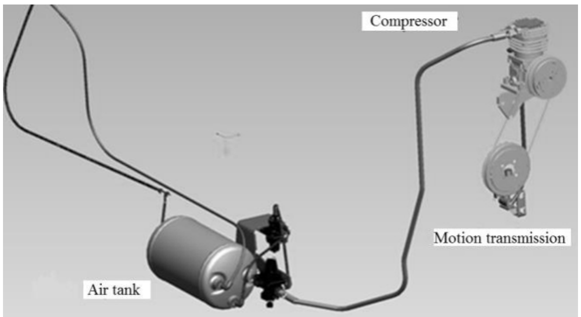

Figure 2. 3D model of compressor and air tube connection

The air tube is a tube which stores the required air to inflate the tires at a specific pressure. It was placed on the right part of the tractor under the tractor cabin.

Tire valves;

Tire valves were connected to the external rim center of each tire and they move independently of the tire. It has two exits, one for air tube and one for tire valve. These valves are put into use in the course of inflation and deflation of the tire with respect to the command coming from solenoid valve.

Pneumatic control unit;

Pneumatic control unit is a unit on which there are 8 solenoid valves including deflation and inflation solenoid valves for each tire. With the commands got from the central control unit, the solenoid valves are put into use in which of the tires the inflation and deflation will be conducted.

Pressure Sensors

The pressure sensors used for each tire are ECT2-2.5A model and they can perform measurement till maximum 72.5 psi of pressure (Figure 3). The measurement sensibility is % 0.2.

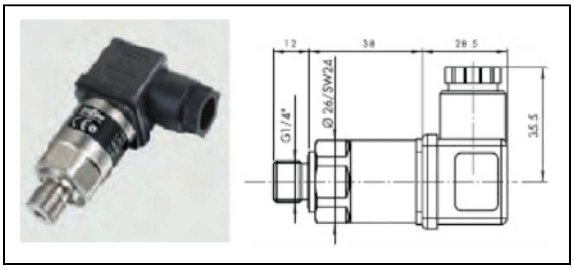

Figure 3. Pressure sensors and their measures

Speed sensors;

5 speed sensors were used in total including 1 propeller shaft and 4 wheels. The speed sensors are the type of proximity NPN 11CF-M1812N-03U2. It has 300 Hz frequency with cable connection and its sensing distance is 12 mm. The speed got from drive shaft is transmitted to the front axle with reduction ratio of 15.73, to the rear axle with the reduction ratio of 26.13. The slippage ratios were determined by benefiting from these reduction ratios.

$$S = \frac{n_t - \frac{n_k}{i}}{n_t} \qquad (7)$$

In this formula;

n_t: Tire speed (min^{-1})

n_k: Drive shaft speed (min^{-1})

i: Reduction ratio

In the designed programme, the comparison is done according to the adjusted slippage ration in advance and the tire pressure is increased if the slippage data got from the tires are lower than this, the tire pressure is decreased if it is high.

The algorithm of the system;

The algorithm of the designed system is given in Figure 4.

RESULTS and DISCUSSION

The production of electronic control unit;

The electronic control unit was designed and produced in compliance with the algorithm prepared in advance (Figure 5). The communication of control unit with pneumatic control unit and the sensors was carried out with ZigBee protocol wirelessly.

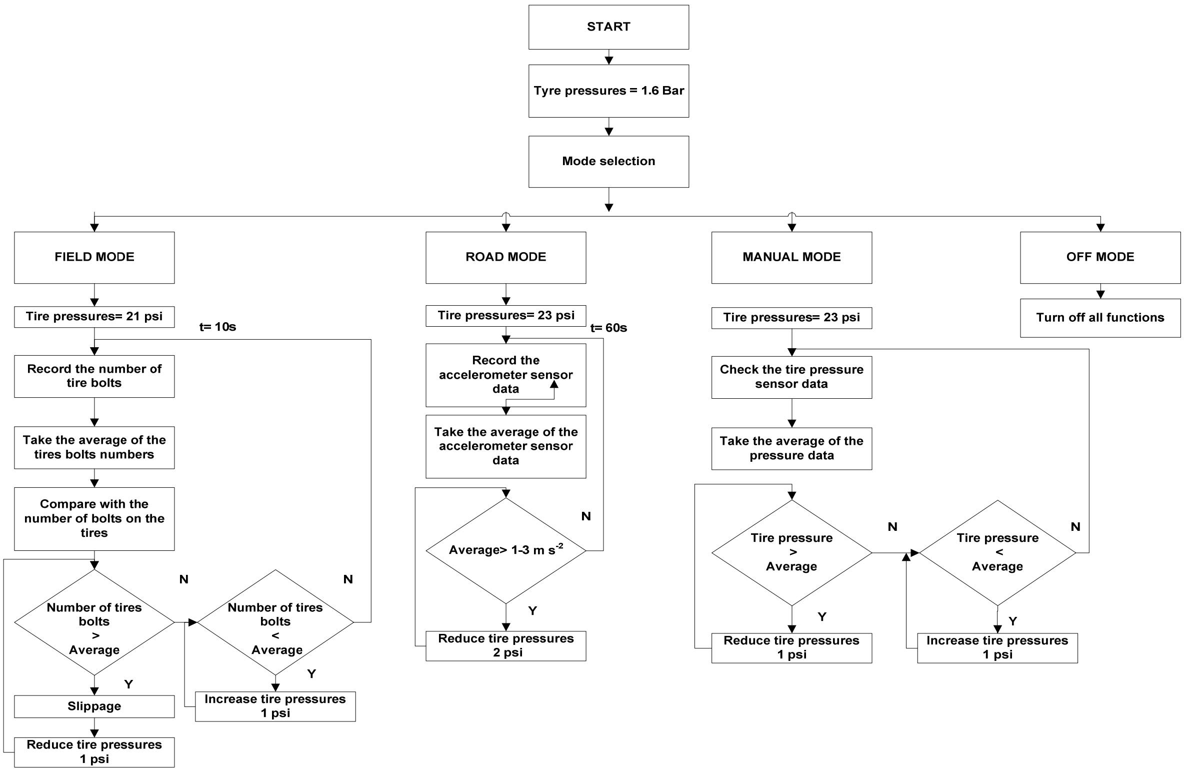

Figure 4. The algorithm of the designed system

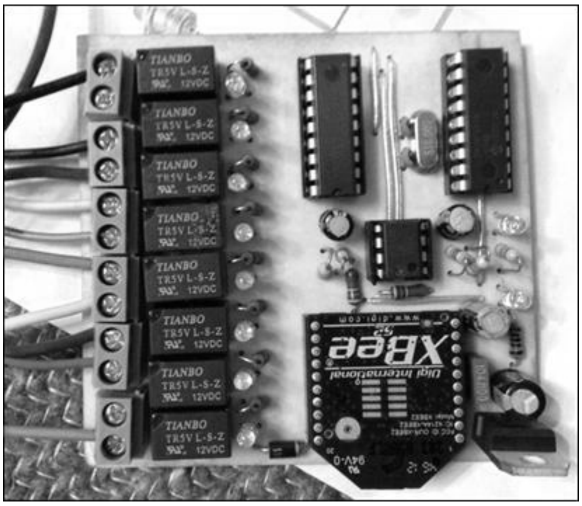

Figure 5. Electronic control unit

Electronic cards providing electronic control unit's communication with pressure sensors were produced.

The communication with tires, main board and control board is conducted by XBee and ZigBee protocols (Figure 6).

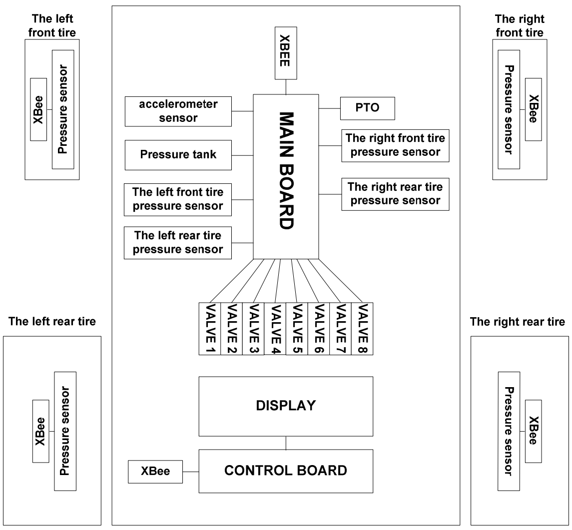

Figure 6. The main scheme of main board and sensor's communication

Main board ; The function of the main board is to measure the speed of tires and tail axle, the compressor pressure and the value of acceleration sensor and to activate solenoids for adjusting tire pressure according to the data got from control board. The module was produced by PIC24FJ32GA002 micro processor. The programme was written in the language of C by MPLAB-C30 compiler.

The control board; collects the data from the modules, activates solenoids by sending data to the main board and gives information to the user by showing the data received on LCD display. The module was produced by PIC24FJ32GA002 micro processor and the giving information was implemented by 128x64 GLCD.

The programme was written in the language of C by MPLAB-C30 compiler.

Tire pressure measurement;

The pressure sensor connected to the tire valve measures the inner pressure of the tire as 4-20mA and sends it to the analog-digital convertor of XBee module. The control board gets these values from XBee modules at intervals of 200ms.

Solenoid valves were put on the base unit of pneumatic control unit (Figure 7).

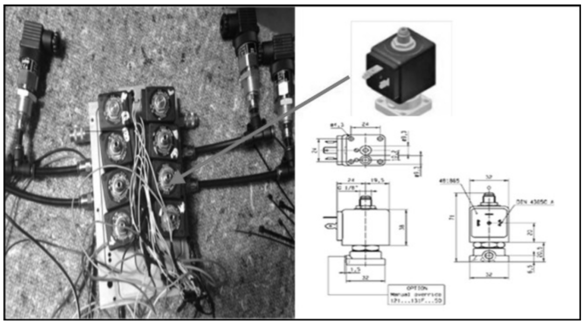

Figure 7. Pneumatic control unit and the placement of solenoid valves

The parts whose production and supply was carried out were mounted on the tractor on which the research would be conducted and the tractor was made ready for the first laboratory tests. It was tested whether the mechanical design of the system and the created product as hardware and software worked properly or not.

The laboratory tests include the tests of the components separately and in the system. The components were tested in relation to supplying design values and the system tests were taken place as a result of getting convenient products.

Firstly, the tractor was tested on the determined test track. Especially tire pressure and tire speed were measured by using auxiliary equipment and working settings of the main system were adjusted with the help of obtained results. Offering solutions to the problems encountered in laboratory tests, the tractor that the system installation was carried out was made ready for operating on the field.

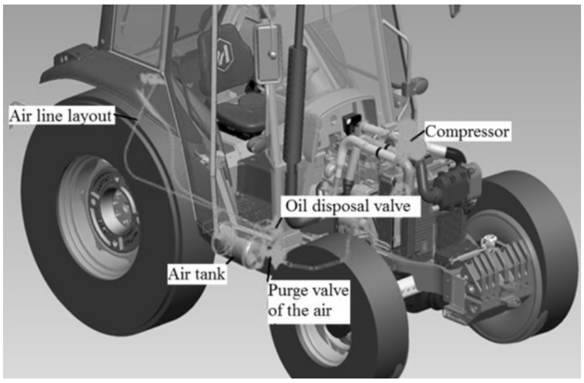

Figure 8. System equipments and installation on tractor

The installation of the system on the tractor;

The installation of the compressor, oil disposal valve, purge valve of the air, air tank of 15 lt and air line layouts on the tractor is shown in Figure 8.

The capabilities of the system were tested by practicing different application conditions under the laboratory conditions in the system tests. Besides, setting up the conditions of possible scenarios which could be encountered on the field, it was provided that the system worked stably against different problems (Figure 9).

Tire valves were installed on the 4 tire hubs of the tractor (Figure 10).

The placement of pressure sensors

In order to perform an accurate measurement, the pressure sensors were placed on by opening a separate valve on the tires. The communication of pressure sensors with central electronic control unit was provided with wireless communication (Figure 10.)

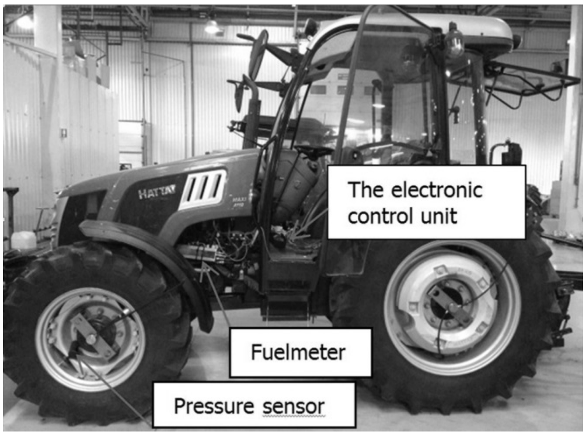

Figure 9. Tire Pressure Control System placed on the tractor.

The controlling of the system;

After the installation had been carried out, the stage of testing the system under the conditions of laboratory took place. The user interface of the designed programme was created and the working of all the tires on inflation and deflation modes was checked. The communication of the system with pressure and speed sensors was taken place without a problem. Moreover, the tires of the system determined 2 psi inflation duration.

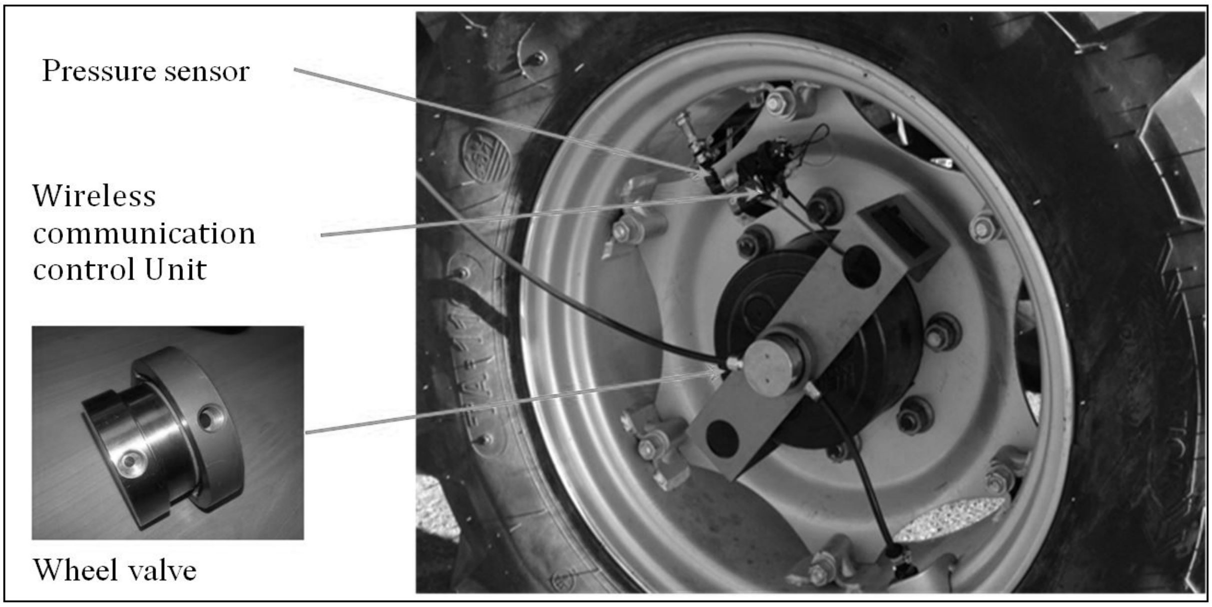

Figure 10. The placement of tire valves, pressure sensor and communication control unit

In repetitive tests, it was found out that one of the front tires required 12 seconds for 2 psi pressure increase and one of the rear tires required 19.7 seconds for 2 psi pressure increase. It was seen that these values were close to the values of theoretical calculations.

Figure 11. The controlling of the system with a computer

CONCLUSIONS

The followings were concluded from the study:

- In the experimental studies carried out, it was determined that the mechanical and electronic parts of tire pressure control system worked successfully.
- The system can be controlled easily by a computer or a developed controller.
- By the help of a digital control device to be placed on the front board of the tractor, the convenience of adjusting and using was provided for the driver.
- As the communication between sensors and control unit was carried out wirelessly, there was no need to use cable and connection components. However, it is seen as a disadvantage to have batteries whose lives are short in the system. Some studies to solve this problem are needed to be carried out.
- In order to understand the performance of the system more clearly, field tests which are the second stage of the study are needed to be done.

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REFERENCES

http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/SAE/SAE2001/ Weinstein.PDF, Website accessed on September 30, 2008

Roundy S., 2008. Energy harvestıng for tıre pressure monıtorıng systems: Desıgn consıderatıons Proceedings of Power. MEMS 2008+ microEMS 2008, Sendai, Japan

Persson, N.; Ahlqvist, S.; Forssell, U.; Gustafsson, F. Low tyre pressure warning system using sensor fusion. In SAE Conference Proceedings on Automotive and Transportation Technology

Fischer M. 2003. Tire Pressure Monitoring,Verlag Moderne Industrie

Hackl S. 2006. Trends bei reifendruckkontroll systemen (RDKS) Vom Komfort zum Sicherheitsfeature, Sensoren im Automobil

Löhndorf M. , Kvister T., Westby E. and Halvorsen E. 2007. Evaluation of energy harvesting concepts for tire pressure monitoring systems of a micro-electric generator for microsystems, PowerMEMS Tech. Dig,, pp.331 -334

Serrano M.J, J.O Peça, R. Sivia, L. Marquez, 2009. The effect of liquit balast and tyre inflation pressure on tractor performance, Biosystem Engineering, Volume 102, P.51-62

Lee K.C., J.H. Yu, Y.G. Choi, H.Y. Jung, K.H. Ryu, 2008. Development of active tire pressure control system (ATPCS) for agricultural tractor-desing of tire pressure transceiver unit using radio frequency, ASABE Section Meeting Presentation, Paper Number : 084520.

Cullen J.D., Arvanitis N., Lucas J., Al-Shamma'a A.I. 2002. I n-field trials of a tyre pressure monitoring system based on segmented capacitance rings. Measurement. 32, 181–192

Craighead I. 1997. Sensing tyre pressure, damper condition and wheel balance from vibration measurements, Proc. IMechE, 211 (Part D) 257–265.

Chen P. et al. 1993. Inspection of tire tread defects using image

processing and pattern recognition techniques, Proc. SPIE, 2063 14–21.

Gros X.E. 1997 Detection of delamination in tyres using eddy currents, Proc. IMechE 211 (Part D) 79–82.

Hill M. et al. 1992. The development and testing of a car tyre pressure sensor, in: Proceedings 25th ISATA Conference on Mechatronics, Florence, pp. 57–64.