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Design, Fabrication and Evaluation A New Mechanism to Automatic Weight Transfer Control System on A Tractor

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DESIGN, FABRICATION AND EVALUATION A NEW MECHANISM TO AUTOMATIC WEIGHT TRANSFER CONTROL SYSTEM ON A TRACTOR

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Abstract

Increasing tractor weight during agricultural operations is one of ways to optimization the performance of tractor tires interacting with soil. One of these methods is adding weight on the front of the tractor, which leads to better engagement of front tires with soil. In four-wheel drive tractors also causes better steering wheel drive tractors, in addition it prevents from weight transfer to the rear of the tractor, which causes overturning. In this research, a new approach has been proposed that proves automatic weight transfer is possible by putting some lightweight instead of main weights on the front of the tractor. To do this, a number of weights to a specified amount were added on the front of the tractor which could be moved by using a mechanical joint and a hydraulic jack (considering working condition and ground conditions). Traction force and slop of land that have the most impact on weight transfer were measured by a dynamometer and an inclinometer. Also the critical values of these parameters were controlled by an electronic circuit. Results prove that the applied system on the tractor was able to control dynamic weight transfer also the longitudinal balance on the tractor was investigated by performing an experiment on a sloping surface, and good results were detained.

Key Word: *weight transfer, safety, critical angle, ballasting, tractor*

1. INTRODUCTION

When farmers buy a tractor, some weights are placed by manufacturers on the front of tractors which should be changed in different working conditions. Adding these weights to the front tractor is due to using the maximum traction power during applying heavy implements and also in order to maintain tractors balance. Weight transfer refers to the changes caused by rear and front reactions of the tractor during drafting a drawbar. Macmillan, R.H. (2002). During lightweight agricultural operation, there is no need to put the heavy weight on the front of the tractor. Farmers are unwilling to change the number of these weights at the beginning of the process (because it's Overwhelming), so increases fuel consumption and leads to early damage of front tires. For this reason an automatic system is needed that depends on working condition and the slope of land, the weights on rear and front tires should be controlled automatically.

Taylor (1980) reported that traction efficiency (TE) of the tractor under the condition of applying drawbar was about 46%, so nearly 50% of available power on tractors axle wasted during power transfer to the wheel. Taylor estimated that 75-80 million gallons fuel could be saved for each 1% improvement in (TE) in 2 WD.

Excessive use of ballasts, not only cause soil compaction but also leads to increase fuel consumption. Now farmers is using static method to ballasting the tractor. Static methods include adding weight to the front and rear tires of tractor and filling tires with water. All of these methods in addition to time-consuming are overwhelming. If a mechanism is designed that could carry out weight transfer easily, quickly, and automatically, then the agricultural process will be done in a high quality. As a result, it reduces soil compaction, prevents from the erosion of tires and also reduces fuel consumption.

In this research, an automatic weight transfer control system is on tractor was fabricated and evaluated which carries out dynamic weight transfer on tractor during the agriculture operation. The position of the weight to optimize the tractive efficiency calculated with micro controller according to dynamic weight distribution.

2. LITERATURE REVIEW

Weight transfer due to the implement installation on the tractor can be caused by drafting the drawbar or joining mounted, semi-mounted or traction implements. Weight transfer can occur without the installation of implements to the tractor by using the tractor in the sloping land, even without installation of anything to the tractor, the smallest awkward move from tractor driver may cause weight transfer from the front to the rear of the tractor, which causes overturning.

In order to improve traction efficiency during the agricultural operation, dynamic weight changing on front and rear wheels is an appropriate way.

It's clear that increasing dynamic weight on drive wheels lead to increase traction force, but it should be noted that increases in dynamic weight on drive wheels shouldn't exceed from the permissible limit in such a way that soil won't be too much compressed and traction won't be limited by the dive of tires in the soil. In increasing dynamic weight on tires, ability to withstand the load should be considered on tires.

Zoz (1972) performed a research on increasing the traction efficiency of the tractor which resulted in a graph for increasing weight in the tractor. According to this research Zoz (1972) has concluded that the maximum traction efficiency occurs in the slippage range of 10-20%, so dynamic weight on drive wheels should be adjusted in a way that wheels slippage will be through this range. Due to the studies of Taylor (1980), traction efficiency of tractors which operate under draft force or there is a drawbar force is about 46%. According to this report, nearly 54% of available power on the axis is lost during power causes soil compression and soil erosion, which for preventing them, a new stage of tillage is needed.

Burt and Bili (1982) have conducted some experts on a tractor with the power of 53 kW, the result of this research show that some factors like changing the ballasting weights, pressure on tires are effective in optimizing traction efficiency and concluded that increasing ballasting weights would cause to more required power, more obtainable traction efficiency in the drawbar and less fuel consumption. Also is reported that the maximum amount of traction efficiency never occurs at the minimum amount of slippage.

According to Lun et al (1984), by changing the type of soil, tires air pressure and using a tractor with the power of 59 kW at 4 surfaces of static load on drive axle (16-26kw) they reach that the higher amount of weight on driver wheels leads to the higher traction efficiency. Also, they reported about 23% reduction in fuel consumption.

Gil and Vonderberg (1968) have proposed a qualitative equation about traction implement, this equation was presented to mathematically describe the variables that influenced on draft force:

$R_n = F(I,D,S,R_v)$ (1)

I: physical properties of the soil (type, texture, moisture)

D: Physical properties of the traction system. (Wheel size, wheel type)

S: Forward travel speed

R_v: Soil reaction to the wheel

Self et al (1987) equipped the rear of a four-wheel drive tractor to a ballasting weight, which could move by a hydraulic cylinder to backward and forward, therefore the ratio of weight distribution on front wheels varies from 35-47% amount of TE depends on the ratio of rotation speed of rear and front wheels as well as dynamic weight distribution.

Davoodi et al (1995) developed a laboratory sample for automatic weight distribution on a 2WD tractor which by simulating a tractor in the laboratory. The vertical force on front axle was investigated by a computer information system. In order to weight transfer on the front and rear wheels, some weights were added on sides of tractor which could move by two rails and an electromotor. Thus, the specimen was studied and tested on Labrador scale, but never installed on a real tractor.

According to Clark and Vandelinde (1993), for making the tractor heavier, using liquid-filled tanks with the volume of 140 liters on each wheel are effective.

Zang and Chenslure (1988) used a new method for weight distribution on the tractor. In their proposed system, for controlling weight transfer, they installed 2 weights of 500kg on both sides of the tractor on two rails. By moving these weights to backward and forward along the longitudinal direction, the process of weight transferring took place. Their experiment proves that when the dynamic weight on front wheels reduces from 30% to 10% of tractors weight (on 2WD tractor), traction performance, fuel consumption and agricultural operation duration enhanced between 2% to 20%.

Tan et al (1994) performed their experiments on a 2WD tractor. Two water tanks, with the capacity of 757 liters, were installed on the front and rear of the tractor. The rear tank mounted on a three-point hitch system and the front tank was mounted on a pre-designed frame on the front part of the tractor. They used a 24 L/min water pump to control the entering water to the tank and also applied four solenoids to control the flow of water into the tanks. The total weight of adding the system to the tractor (weight of tanks, weights of solenoids, water pump and the attached frame to the front of the tractor) was about 282 kg. So it was considered worthless against the total weight of the tractor (58628 N). They also applied a monitoring system to display weight on the front axle, ground condition, and tractor safety. The result of their researches showed that their proposed system not only reduce slippage and kept it on the peak of traction efficiency graph, but also increased the amount of traction efficiency, and due to low agricultural operation during it prevented from high fuel consumption.

3. MATERIALS AND METHODS

In the past, most tractors were designed as 2WD tractors and usually the rear axle was considered as the drive axle. To increase the traction force in tractors manufactures began to design front-wheel drive tractors and produced 4WD tractors.

Weight directly affects the traction efficient of the driver tires of tractor. The meaning of this sentences is that the weight directly affect the traction that is produced by driver tiers. So that, if a 4WD tractor doesn't have an appropriate weight on the front fires during agricultural operation, traction and into the steering wheel disturbance can to the slippage. So by considering drawbar force, drawbar condition, the slope of ground and the type of implements attached to the back of the tractor, there should be on estimation about the load on the front wheels and the following equation can be used (Wisme and Lut 1974).

$$R_n = w\left[0/75(1 - e^{-0/3B_n.s})\right] - w(\frac{1/2}{B_n} + 0/04) \quad (2)$$

Where:

W: Vertical force on wheels from the soil (KN)

R_n : Traction force(KN)

B_n: Mobility number

S: Forward travel speed (m/s)

The above equation simply states that traction force is directly related to the weight on drive tires, but according to the last clause, related to the rolling resistance, it's observed that increasing weight can lead to increase in rolling resistance value which ultimately reduces traction force. This equation apply on the driver tires of tractor.

In this paper, to avoid this, the critical drawbar force is considered as final draft force and the critical angle of tractor used for longitudinal equilibrium.

In this research, a MT-250 4WD tractor was used and the specification of this tractor is shown in the following table.

Table 1 – MT 250 four-wheel drive tractor specifications

Power	Model	Weight on the rear axle	Weight on the front axle	Total weight
25hp	MT 250	500 kg	435 kg	935 kg

For this tractor, due to the static weight distribution, the critical drawbar force is calculated about (20KN).

For calculating the critical angle of the tractor the following equation was used: (Macmillan, 2002)

$$\beta = \beta_1 + \beta_2 = \tan^{-1}\left(\frac{r_r - \mathrm{r_r}}{x}\right) + \tan^{-1}\left(\frac{y' - \mathrm{r_r}}{\mathrm{x}''}\right) \qquad (3)$$

$$y_g = \frac{x_r - \mathrm{z}}{\tan\beta} = \frac{x_r - \dfrac{\mathrm{x'_r}}{\cos\beta}}{\tan\beta} \qquad (4)$$

$$\tan\theta_{critical} = \frac{x_r}{r_r + y_g} \qquad (5)$$

As shown in figure (1), critical angle (θ) (in which tractor overturn), rear wheel radius (r_r), front wheel radius (r_f), horizontal distance between two centers of front and rear wheels (x), height of centers of front wheels from ground in raised condition (y'), horizontal distance from the center of the rear axle to the center of front axle in raised condition (x_r), height of center of gravity from: ground (y_g), and horizontal distance between the rear axle and center of gravity (x_r) are measured. Also due to the Eq. (4), the value of the critical angle is calculated. (Macmillan, 2002)

In order to measure the traction force during the field operation, a three-point hitch dynamometer was used which the dynamic draft force measured by the attached strain gauges on it and they're resultantly considered as draft force

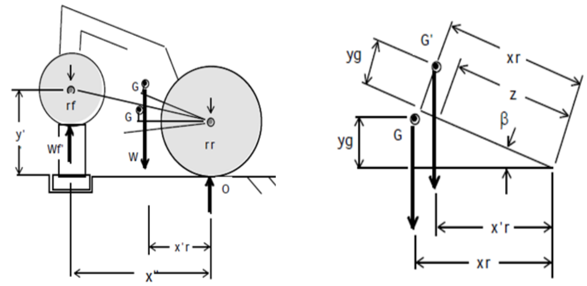

Fig. 1. Center of Gravity Distribution of tractor weight on front and rear tires (right) Free diagram of section (left)

3.1 AUTOMATIC WEIGHT TRANSFER CONTROL SYSTEM

For an appropriate weight distribution on 4WD tractor in the static state, 60% of tractor weight should be on the front wheels. According to the physical specifications and weight distribution of this tractor (MT-250 4WD), some ballasting weights (aproximatly100kg) were used then by a hydraulic jack and fixed arms these weights attached to the front of the tractor. Figure (2) displays a designed and software 3D model and other components of this system.

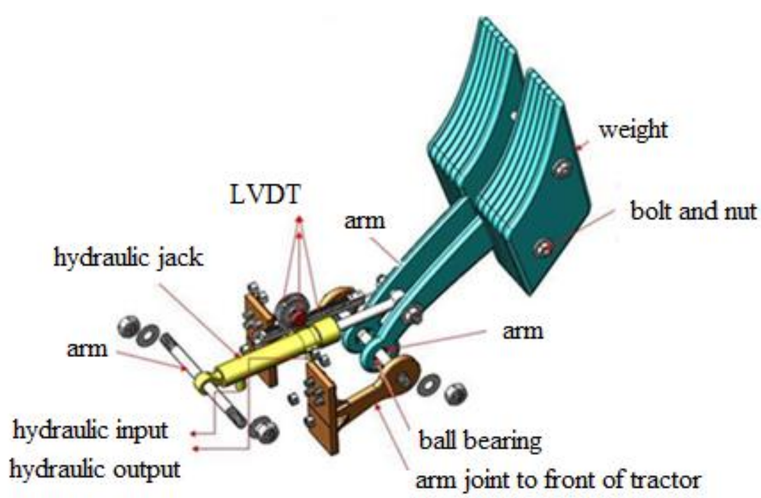

Figure 2. Components of the Automatic Weight Transfer Control System

In this system, the hydraulic cylinder which is attached to the weight by pin joints can open and close the hydraulic jack and move the centers of gravity of weight to the front of the tractor, also it can change the amount of torque on front and rear tires by increasing the distance between the center of gravity of wheels and front axles of the tractor.

The advantage of this mechanism is that instead of using many ballasting weight on front of the tractor, a few weights can be used. Due to the working conditions, the distance between weight and the front of the tractor can change by a hydraulic jack and causes dynamic weight change of tires.

3.2 HYDRAULIC SYSTEM

In order to controlling the hydraulic system, an electrical hydraulic valve, a flow control valve, a pressure reducing valve (PRV), a manometer were used. Figure (3) shows the hydraulic circuit components. Output and input of this hydraulic system are controlled by an electronic circuit.

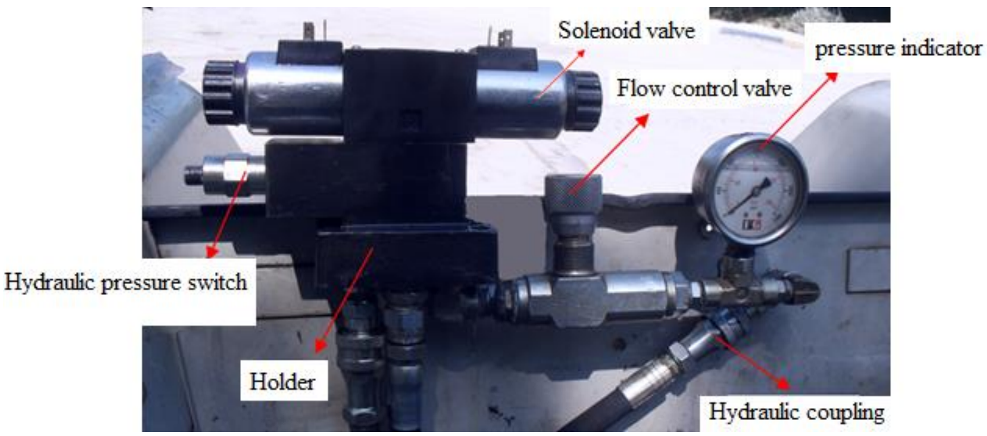

Figure 3. Components of hydraulic system

3.3 DETECT THE SLOPE OF LAND

In order to measure the slope an electro- magnetic inclinometer was developed. Figure (4). The Inclinometer includes a Mira pendulum that has been changed by changing the magnetic field, when the slope of land changed.

Pendulum consists of a plastic page that both sides of that. The permanent magnets were installed. In order to measure the angle of slope the kmz41 and uzz9000 sensor were used. A capacitor with 470 nf was used to decrease the noise. The inclinometer installed on chassis of tractor according to following picture. Figure (4) and (5), respectively show the internal view of the inclinometer, sensor circuit, and drive chip. The inclinometer was installed on side of tractor.

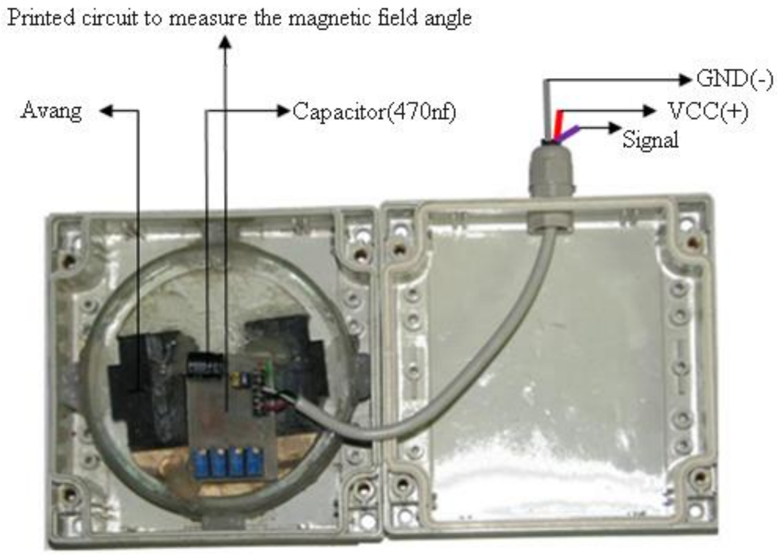

Figure 4. Inclinometer

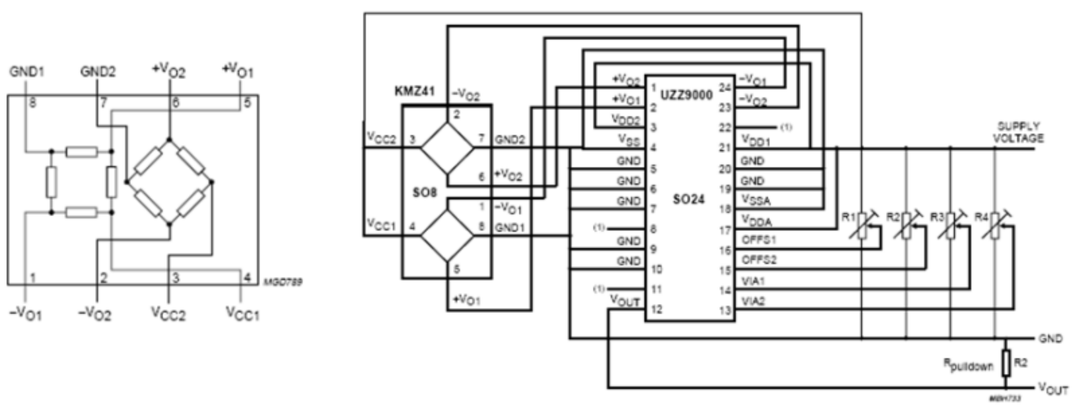

Figure 5. The circuit of KMZ41 sensor and UZZZ2000 that used in inclinometer

The whole system immersed in glass box and glycerin oil. The glycerin used as a damper and the output of inclinometer connected to one of the input terminals of the control circuit, all of these were in order to measure the gradient of any given time and enter it to the control circuit.

According to (Nichol et al, 2005) studies, researchers a claim that by using cheap micro electro machine system (MEMS) sensors and two axes accelerometer, they can manage and control tractors condition. In addition, they have designed a color (LCD) visual display that helps the operator to be aware of the stability condition of the attractive. Rear overturn can be caused by a variety of unsafe conditions ranging from driving up a steep slope land or over an obstacle, improper high hitching of 3-hitch point implement or chain, or rapid clutch actuation and excessive engine torque while pulling an implement. (Sommer and et al, 2006).

3.4 CONTROL CIRCUIT

In this study, a micro control system and an IC drive for AT mega 32 were used. The following diagram illustrates output and input of the control unit of

Automatic Weight Transfer Control System on the Tractor. There are two input for central control unit: slope of land and draft force. The critical angle of tractor and critical draft force were calculated according to MT250-4WD tractor specification and these parameters measured by inclinometer and dynamometer respectively and the amount of these parameter were monitoring with a LCD monitor for operator of tractor. According to draft force and critical angle, the solenoid valve actuated and hydraulic jack opened Suitable.

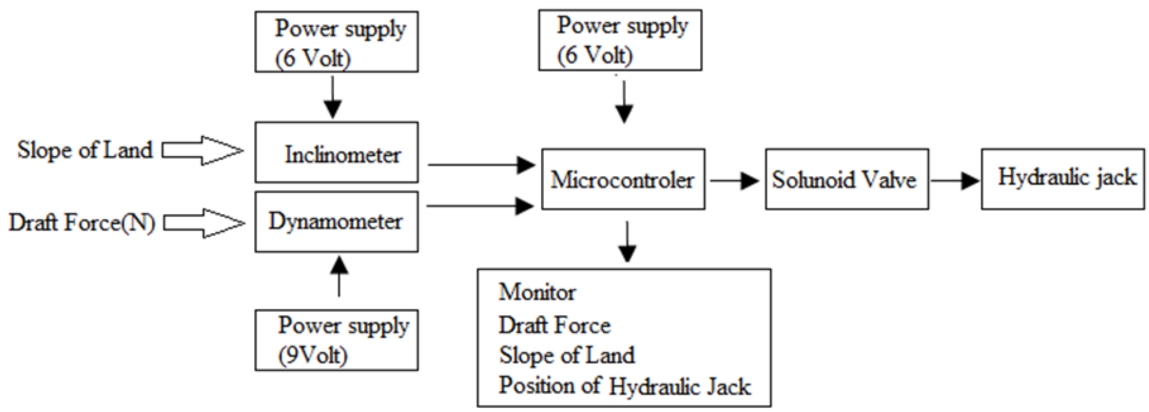

Figure 6. Block Diagram of Automatic Weight Transfer Control System

4. DYNAMIC FORCE ON FRONT WHEELS IN THE DYNAMIC STATE

Hydraulic cylinder can be opened and closed with a command of a microcontroller and the amount of opening and closing of this hydraulic cylinder depends on the applied drawbar force and the slope of the ground. There is given a program to the microcontroller that commands to the electric valve, so the oil flows and the hydraulic cylinder returns to calculated valve, microcontroller allows the electricity to flow in the hydraulic valve unit it achieves to the calculated weight on the front tires. According to the calculations, in order to achieve to the maximum traction efficiency for a 4WD tractor. Free graph of applied forces on the tractor, by considering a longitudinal slope is shown below. (F_d is the applied drawbar force figure 7).

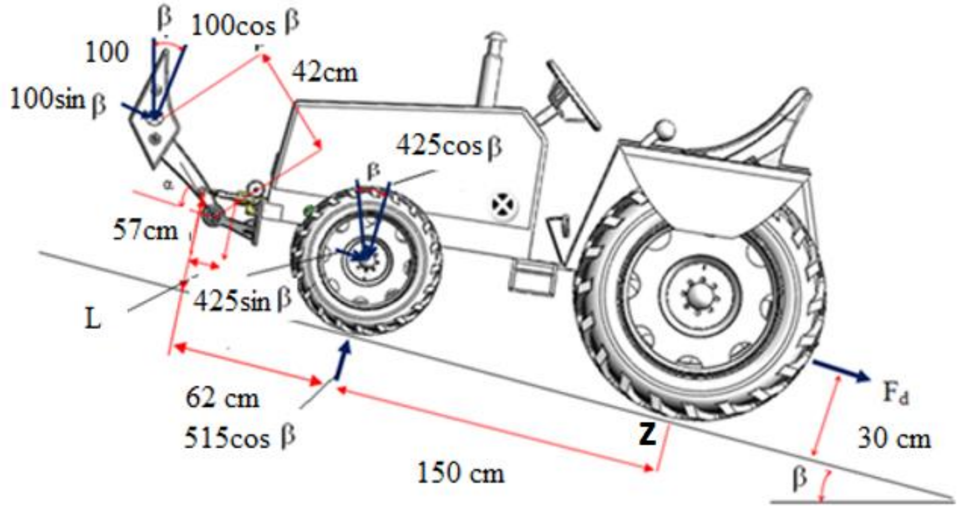

Figure 7. Free Diagram of Total force on tractor on slope

Torque around the point of (z) reliance on the rear wheel and ground, below equation applied:

$(30).F_d+(515).(150)(\cos\beta)+(100)(\sin\beta).(\sin\alpha).(435).(35)(\sin\beta)= (435).(150)(\cos\beta)+(100).(\cos\beta).[50+62+L+(42)(\cos\alpha)]$ (6)

4. RESULTS AND DISCUSSIONS

The mechanism installed on front of tractor and was evaluated with plowing operation and on sloping ground, considering that drawbar force is measured by a dynamometer. It is observed that with increasing the drawbar force, hydraulic cylinder opens and with increasing the distance of center gravity of weight from the front axle, weight transfer occurs and leads to the constant weight on the front wheels. Figure (8) illustrated the plowing operation with installed Automatic Weight Transfer Control System.

Figure 8. The field testing of Automatic Weight Transfer Control System

Drawbar force was measured at the speeds of 2.4-1.2 m/s and for 15cm plowing depth, also in forward travel speeds of 2.41-0.76 m/s and 25cm plowing depth for one-harrow moldboard plow in the field. The fig (9) illustrated the output of dynamometer verse speed.

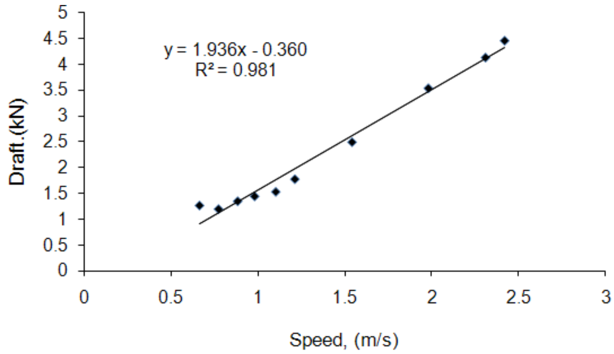

Figure. 9. Draft force versus speed changes with using the Automatic Weight Transfer Control System

Whereas one of the advantages of this system is keeping the longitudinal balance of the tractor on the sloping ground. For evaluating this subject tractor is taken on a sloping ground. Each tractor overturns in a special angle, to avoid this, some appliances are considered. In this study, regardless of increasing the slope of ground and decreasing weight on the front wheels of the tractor, hydraulic cylinder opens and the weight moves to the forward to prevent from the rear overturning of the tractor. A monitor is applied for displaying the unstable condition of the tractor, by using an inclinometer and a given program to the microcontroller, whenever the slope of ground exceeds from 25 degrees, the red color of light beside the monitor starts flashing, so the tractor driver can react in order to prevent an accident. For testing this system on the sloping ground, tractor was taken on sloping ground and observed that with increasing the slope of ground and due to the microcontroller calculations, the electric hydraulic rove gets excited and with opening the oil path in the hydraulic circuit, hydraulic jack opens, so by increasing the distance of center gravity from the front part of tractor, weight transfer to the front part takes place. According to the given program to the microcontroller circuit, in order to maintain the longitudinal balance whenever the measured gradient from 28 degrees, hydraulic jack opens completely and locates in its final course, in when we will have the maximum weight transfer on the front part of the tractor. The Figure (10) illustrated the field testing of this mechanism on slope land.

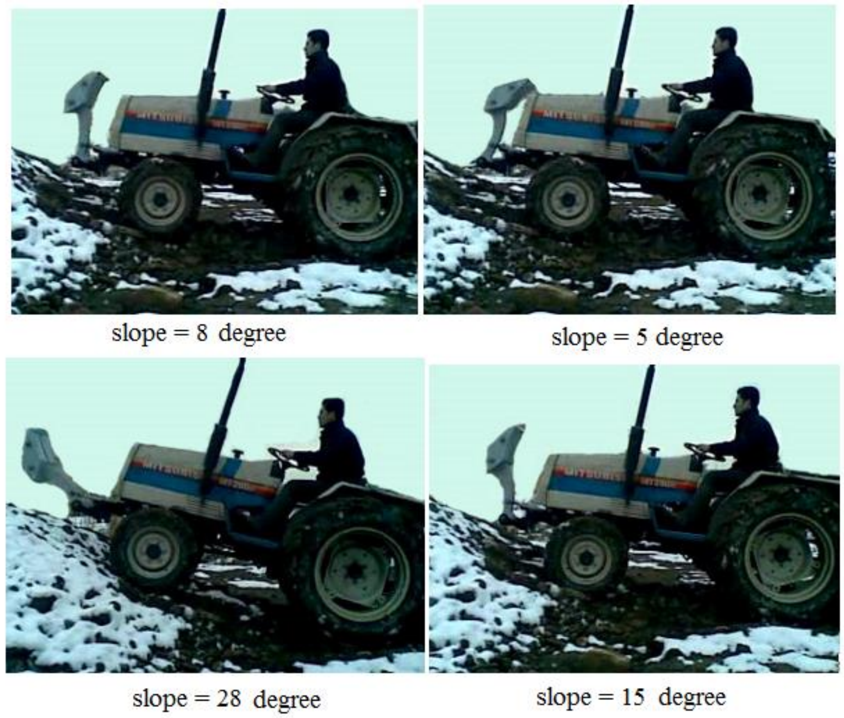

Figure 10. Testing of mechanism on slope land

5. ADVANTAGES OF THIS MECHANISM

1) Considering the presented designed principles in this research and according to the type of tractor, with small changes, this mechanism can be installed on all 4WD tractors.
2) This system have the simplest mechanism and hydraulic system have been used and then keeping it is easy, repairing is inexpensive and also takes a little time.
3) Due to the dynamic weight on a 4WD tractor, the traction force which is produced by front wheels, optimizes with using automatic weight transfer control system.
4) The critical drawbar force of tractor can be increases about 42%.
5) Considering the installation of this system on all 4WD tractors, we can use less weight on the front of the tractor and eventually prevent from high fuel consumption.
6) Due to the automatic control operation, appropriate weight distribution is carried out automatically and there is no need for the attention and accuracy of the driver.
7) With installing this system on the tractor, better steering of wheels takes place.
8) With installing this system on the tractor, avoid from rear overturning by maintaining the longitudinal balance of the tractor.

6. CONCLUSION

In this paper, a new mechanism was designed and fabricated in order to dynamic weight transfer on the wheels of a 4WD tractor. In this method, the basis was applying the low amount of ballasting and automatic weight distribution on wheels. To have the maximum traction efficiency in 4WD tractors, dynamic weight on front wheels should be 50% of total weight of the tractor. Due to the static weight distribution, the required amount of weight to weight distributes is estimated drawbar force and slope of ground which are effective parameters of weight transferring in the tractor, measured by some speed tools. Measuring applied forces on the tractor for improving productivity and efficiency of the tractor is an inevitable issue, therefore we tried to review this subject in this paper. Due to the significant advances in the electronic fields, accuracy advances in the electronic fields and speed of information processing, was tried to take advantage of method tools in controlling and measuring. In this research, there is an estimation of required weight for automatic transfer which is based on the static weight for MT 250 Mitsubishi 4WD tractor, but not that the amount of required weight on another model of the tractor may be different, but in general, by considering the mentioned designed principles in this research, proposed system, by small changes like the type of selected tractor, can be installed on all 4WD tractor and farmers can use the advantages of these methods.

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