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Design Of An Advanced Three-Point Hitch Dynamometer

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ABSTRACT: Measuring the powers produced in the tractor's arms as a result of tension of the agricultural equipments is important and necessary. These quantities can be used in agricultural machineries test, selection of a suitable tractor and as likes. The tool used for measuring these powers is called dynamometer. In this project, an advanced three-point hitch dynamometer was designed for 'John Deere 3140 tractor'. Installing some transducers on the upper and lower arms, the pressing, tensional and vertical forces were measured in this dynamometer. The sensitive parts of these transducers are the square section pins, upon which some strain gauges are installed to measure the power. An optical encoder was also considered to measure the angle of tractor's arms, so that the components of power in different directions could be obtained. The measurement accuracy was considered as an angle of 0.5 degree. Other angles of arms are determined by this angle and the geometry of tractor-equipments. The instantaneous speed of the tractor is determined by a speedometer installed on the front wheel of the tractor to specify the consuming power of the equipments. An appropriate data logger was chosen to record data continuously. Data access speed in this dynamometer is 20Hz. The error of speed measurement in this dynamometer is less than 2.5%. This dynamometer does not have the errors usually faced in other dynamometers such as reciprocal sensitivity and hitch point changes. Also its manufacturing cost is less than other similar dynamometers. [Journal of American Science 2010;6(9):303-311]. (ISSN: 1545-1003).

Key Words: Three-point hitch dynamometer, Data Logger, Speedometer, Advanced

INTRODUCTION:

Nowadays, a considerable part of energy is used for agricultural activities and their mechanization, and an enormous sum is also spent to provide required powers of mechanization. Reports on the amount of energy consumption in the U.S.A. indicate that about 12% of total energy consumption is allocated to agriculture and related food chain activities and that the real consumption in agriculture is about 3% of total energies.

More than 50% of this energy is consumed in tillage part, annually applies to more than 225 billion ton of soil. In order to plow this amount of soil, we will need 2 million liters of gas oil (Smith & Barker, 1995).

Measuring the power and tension of soil cultivation implements in different situations are useful for selecting the tractor and instruments for various agricultural functions. Informational data are essential for domestic producers and manufacturers of agricultural machines. Implements' size can be in conformity with available tractors in the country by measuring the informational parameters of tractor such as tension power. This information can be useful for the assessment of various mechanized systems in agriculture. Manufacturing factories of agricultural machineries and agricultural producers can use the information on "necessary power and tension resistance of soil cultivation implements in various soils" to determine the appropriate size of tractor. Farmers mostly select tractors and implements for the various agricultural functions based on their experiences. These earlier experiences may have less impact on the selection of new implements. Therefore, data about tension resistance of new implements in various soils and situations can be an important factor in tractor and agricultural implements selection (Al-janobi et al. 2000).

A three-point hitch dynamometer is needed to measure the tension resistance between tractor and assembled implements. Most of the three-point hitch dynamometers have been designed and manufactured since 1960. In all of the recent designs, resistance strain gauges have been used for measuring the forces in special constructed load cells. Some designs measure all of the force components incoming to implements by dynamometer, some others measure only horizontal and vertical forces but lateral small forces are overlooked. Most of the systems measure only horizontal force (strain). Generally, dynamometers can be classified into two major groups: frame and linking.

Frame dynamometers are containing load cells, installed on a special frame, placed between tractor and implements. In other words, frame is designed in such a way that from one side, it is connected to a tractor and from the other side to the implements. The main advantage of the frame dynamometer is that it is not for a special kind of

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tractor. However, the frame dynamometers have many defects as followers:

1-There is a need to making a special frame which is a very difficult, time consuming and costly task. As its parts are very big and heavy, in the other hands, they need a high accuracy not to cause problems while being connected to the tractor and linking the implements to them.

2- The frame displaces the linking point of implements to the tractor about $200\text{-}300_{m.m}$ backward. This displacement completely disorders the status of exerted forces on tractor and makes small and large errors, depending on the displacement amount.

3- Frame weight can be over 200_{kg} which has an important role in exerted forces on the tractor and weight transmission that by itself causes error.

4- Frame makes problems in connecting implements, such as difficulty in implements connection because of frame inflexibility, problem in connection of PTO axis in situation of frame unsuitable design.

Instead, linking dynamometers have the following advantages:

1- Lack of design frame makes its construction simple with a lower cost.

2- It never disorders the exerted forces on tractor and does not make errors.

3- It has a better flexibility while performing implements connection to tractor.

4- It does not make any problem in establishing of PTO axis.

Considering the need of country, advantages and good accuracy of linking dynamometers, we designed an advanced linking dynamometer.

METHODES AND MATERIALS:

Linking dynamometers should be designed for a special tractor; therefore in order to test larger implements, John Deere 3140 tractor was selected among the available tractors in the country because of their prevailing usage and their appropriate power (95 horse powers). In addition, the form of its lower arms is such that, it makes easier designing of dynamometer transducers.

This dynamometer has transducers, installed on lower arms measuring the forces in horizontal and vertical directions. In addition, by installing strain gauges on the upper arm, its axial force can be computed.

In order to analyze the measured forces in direction of tension and vertical forces, the arms angle should be determined in relation to horizontal and vertical plane of tractor. For this reason, angle-computing system was designed to specify lower links angle in the ratio of horizontal plane.

Considering the geometry of tractor and implements, the angle of lower arm in relation to vertical plane of device and upper arm angle in relation to horizon are measurable.

For measuring the tension power of tractor, in addition to measuring the tension force, we need instantaneous velocity. In order to measure the instantaneous velocity, a velocity meter was installed on the front wheel of tractor. A data collecting system was selected for collecting data.

Forces in linking points of assembled implements

In the assembled implements, the device is connected to the upper hitch point and two lower hitch points of tractor. In the upper hitch point, force is exerted only in the direction of the axis of upper arm (F_t), but in two lower hitch points, forces are in three directions: in direction of arm axis (F_{blh},F_{brh}), perpendicular to the arm direction (F_{blh}, F_{brh}) and lateral (F_{brs}, F_{bls}) [Figure1-left and middle & Figure 2].

The mentioned forces should be analyzed according to the arms angles, and their components should be obtained in directions of tension (F_x) and vertical (F_y) [Figure1-right].

Then, the tension force (F_x) can be obtained through algebraic sum of horizontal components, and vertical force (F_y) by algebraic sum of vertical components

Considering arm angle in the ratio of horizontal plane (a), the axis force of upper arm is analyzed to its components in the direction of tension (F_{tx}) and vertical (F_{ty}) [Figure2].

$$F_{tx}=F_t \cdot \cos a \qquad (1)$$
$$F_{ty}=F_t \cdot \sin a \qquad (2)$$

Lateral forces usually can be overlooked in comparison with the horizontal and vertical forces; in addition, these forces are less emphasized in analysis except on special cases. On the other hand, for measuring this force, device encountered so complexity in constructing. For these reasons, measuring the lateral forces was given up.

We can obtain axis (F_{brx}, F_{blx}) and vertical forces (F_{bry}, F_{bly}) in lower arms (Figure 4), if we overlook the lateral forces and consider two presented angles in Figure 3.

$$F_{blx}=F_{blh} \cdot \cos b \cdot \cos c - F_{blv} \cdot \sin b \cdot \cos c \qquad (3)$$
$$F_{brx}=F_{brh} \cdot \cos b \cdot \cos c - F_{brv} \cdot \sin b \cdot \cos c \qquad (4)$$
$$F_{bly}=F_{blh} \cdot \sin b + F_{blv} \cdot \cos b \qquad (5)$$
$$F_{bry}=F_{brh} \cdot \sin b + F_{brv} \cdot \cos b \qquad (6)$$

Computation of tension and vertical forces

Tension and vertical forces are obtained through algebraic sum of their components in three linking point:

$$F_x=F_{tx} + F_{blx}+ F_{brx} \qquad (7)$$

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$F_y=F_{ty}+F_{bly}+F_{bry}$ (8)

Substituting (1), (3) and (4) equations into equation (7), the tension force is obtained:

$F_x=F_t \cdot \cos a + F_{blh} \cdot \cos b \cdot \cos c - F_{blv} \cdot \sin b \cdot \cos c + F_{brh} \cdot \cos b \cdot \cos c - F_{brv} \cdot \sin b \cdot \cos c$ (9)

Also by substituting (2), (5) and (6) equations into equation (8), vertical force is obtained:

$F_y= F_t \cdot \sin a + F_{blh} \cdot \sin b + F_{blv} \cdot \cos b + F_{brh} \cdot \sin b + F_{brv} \cdot \cos b$ (10)

Now by measuring the axis force (F_{brh}, F_{blh}), perpendicular to axis (F_{brv}, F_{blv}) lower arms and axis force of upper arm F_t) and angles of upper and lower arms (a, b and c), the values of tension and vertical force can be computed.

Measurement of force in lower arms:

For measuring the forces of arms, one load cell was designed for each arm. Considering the point that lower arms of John Deere 3140 tractor are two-pieces (Figure5), load cells were designed in such a way that just the final small part of tractor to be changed for locating of load cell. Designed load cell (Figure 6) is located in the sliding part of lower arm (F.5-left), instead of locating in final part (F.5-right). This method is much desirable because of its more simple construction and accuracy of device and that it does not make any problem in geometry of tractor-implements. Efforts were made to consider the best design for the parts of this load cell, so that in addition to suitable tolerance of forces and no increase of maximum stress beyond the acceptable point in the part, the weight of part not to rise and the part to be constructed easily. After designing some model for this part and analyzing the limited components of these parts at most severe situations, and computing the weight and method of constructing, this model was selected. Concerning the tolerance of forces, weight and construction method, this piece is in optimal condition.

CATIA V5R7 software was selected for designing and analyzing the limited components. The reason for this selection is its high ability in modeling. It is such that the designing environment of this software is much more advanced than available ones. High editing ability of this software is the main reason of selecting it for modeling and analyzing the limited components. Editing the parts in the software is too fast and with a high accuracy and defect is little.

Due to the fact that so many changes were needed to get the best form in designing of this load cell, working with other available software's was impossible because of their lower speed and accuracy and much defects. Every part was tested after creation in the designing environment of this software, according to needs and situations of device in the analysis environment of its limited components and available charges in order to avoid any problem in the tolerance of the exerted forces. To get the best form, so many models were designed and analyzed and finally this model was selected, since it can resolve the needs of our device and has a suitable construction costs.

Pins

Four pins are located at the main part of the transducer to sense the force and control the hollow sphere part in vertical and horizontal directions. Strain gages are installed on these four pins. The reason for selecting the square form for these parts is the accurate installation of strain gages (F.7).

For designing the load cell of the lower arm, force created in this arm should be computed. In order to determine the maximum tension force which is exerted on implements by the earth, a six-bottom plow was selected, every bottom with operation width of 40cm and 30cm depth at 7/2 km/h speed in the loamy soil. By this method, the maximum created force in both arms of tractor was 167400N and therefore in each arm, it was 83700N.

Force in lower arms is sensed by the strain gages that are installed on pins. It was decided that the stress does not go beyond 200MPa.

$$\sigma = \frac{P}{A} \Rightarrow A = \frac{P}{\sigma}$$

$$A = \frac{83700}{200\times10^6} \Rightarrow A = 0.0004185\text{m}^2$$

Supposing that pins section is square, we have:

$$A = a^2 = 4.017\times10^{-4} m^2 \Rightarrow a \approx .02m = 2Cm$$

The accuracy of device can be increased by using the steels with lower elasticity modulus. One of the abilities of this dynamometer is its changeable pins. Accuracy in measurement can be increased by the substitution of pins with smaller cross section. Of course, selected pins for load cell should have a suitable tolerance in the face of the exerted forces. Generally, for measuring the forces of smaller implements, we can use pins with a less cross section in order to increase the accuracy of measurement.

Measurement of force in upper arm

Considering the fact that in the upper arm, there exists only the axis force, so measuring its forces is easier. These axis forces can be measured by installing the strain gages on the arm (Derafshi & Mardani, 2003). At the end of upper arm of John

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Deere 3140 tractor, there exists a rectangular solid part which is suitable for installing the strain gages.

The selection of strain gauge

Strain gauges were selected from Japan TML company's products because of their quality and availability. All strain gauges of this dynamometer were selected from FLA-10-11 kind. Considering the location of the strain gauges and amount of available room on force sensor pins, the installation of this kind of strain gage with regard to its dimensions is suitable. Its installing method is easy and its price is lower in comparison with other strain gauges. In addition, the maximum strain on pins is lower than the acceptable maximum strain of strain gauges.

The circuits of strain gauges in the upper arm

If you consider the Figure 8- Left as a cross section of upper arm, the strain gauges are installed according to this Figure. In addition, two strain gauges, R3 and R4, are installed instead of R1 and R2 at the front face. This kind of arrangement is used to increase the sensitivity and eliminate the temperature effects. According to the Figure 8-Right, we locate strain gauges on an electrical circuit.

The circuit of strain gauge in the lower arm

Two pins have been designed in lower transducer to measure the forces in any direction. At the time of charging, one of the pins will be under pressure and the other one will be in an uncharged state. Four strain gauges were located on every pin. Strain gauges in the pins under the pressure are to sense the strain and in uncharged pins are to complete the electrical bridges and eliminate the temperature effects. Arrangement method of strain gauges, electrical circuits of two axis direction and perpendicular to axis are the same.

Strain gauges, according to Figure 9-Left, are installed on the middle of presented face. The method of labeling the strain gauges on the pressured pin is in the following manner. The two other strain gauges are installed on the front face of pin like this very face, such that R3 strain gauge is located instead of R1 and R4 instead of R2. In addition, R5 instead of R1, R6 instead of R2, R7 instead of R3 and R8 instead of R4, are located on the uncharged pin. Arrangement method of strain gages are according to Figure9-Right. This arrangement in addition to having a maximum sensitivity eliminates the effects of temperature as well.

The measurement of angles of the upper and lower arms

In order to analyze the measured forces in the upper arm and load cells of lower arms, we are in need of different angles of these arms. Three angles (a, b and c) have been used for analyzing the forces in different directions.

The lower arm angle with a horizontal plane (b)

Optical sensors were selected for assigning this angle. This method has a very suitable accuracy of measurement, because the accuracy of measurement is very high in comparison with other dynamometers. Also, it is very easy to construct it. The lower arms move approximately 16 degree. For having 0.5 degree of accuracy suitable for our task, we are in need of 32 statuses which are obtained by five bands ($32=2^5$).

The lower arm angle with a vertical plane(c)

We use the tractor-implements geometry to determine this angle. According to Figure10, we have:

In Figure10, n is the gap between the two hitch points of tractor after linking the implements (centimeter), m=gap between two hitch points of lower arms to chassis (centimeter) and l=length of lower arm (centimeter). So angle c is obtained from this equation:

$$c = \sin^{-1}\left(\frac{\frac{n-m}{2}}{l\cos b}\right)$$

The upper arm angle with a horizontal plane (a)

Considering the geometry of tractor-implements, this angle is measurable, too. Having the information of Figure11, we can identify the angle (a) from geometry of tractor-implements.

In Figure11-Right, l=length of lower arm, m=vertical distance of connection points of lower and upper arms to the tractor, n=distance of the upper and lower connecting points to implements in vertical plane of a tractor, o=horizontal distance of upper and lower arms` connecting points to the tractor, p=length of the upper arm. According to Figure11-Right, we will have:

$$q^2 = (m + l.\cos c .\sin b)^2 + (l.\cos c .\cos b \;\; o)^2$$

$$r^2 = m^2 + o^2$$

$$t = \cos^{-1}\left(\frac{(l\cos c)^2 + q^2 - r^2}{2ql\cos c}\right)$$

$$l_1 = 180 - (b + r)$$

$$l_2 = 180 - l_1$$

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$$s = l_2$$

$$(a + s) = \cos^{-1}\left(\frac{p^2 + q^2 - n^2}{2pq}\right)$$

Angle (a) is computed in this manner.

The measurement of the real velocity

For measuring the real velocity, we utilized a rotation gauge installed on the front wheel of the tractor. The front wheel of the tractor has a lower slippage, so it does not make the error as back wheel does. In addition, using the front wheel as compared with the fifth wheel can be more suitable for designing because of lower constructing cost and lower slippage (for a further weight on front wheel). Designing the velocity meter of the device is like determining the upper arm angle is done by an optical encoder system. In determining an angle, we covered just 16 degree, but in velocity meter our circles are complete. Considering the accuracy needed, 11 rings were selected for optical encoder. These 11 rings make 2^{11}=2048 states for us. The accuracy of angle measurement is obtained through dividing 360 degree by 2048 state, i.e. 0.17578125 degree.

We can obtain the linear velocity of the tractor by measuring the value of rotation angle and having the dynamic radius of front wheel (radius during the operation of front wheel), and times between information collecting.

$$v = \frac{\Delta x}{\Delta t}$$

$$\Delta x = \frac{\Delta\theta \times 2\pi R}{360}$$

V: the real linear velocity (m/ s), *Δx:* propelling value (meter) *Δt:* time duration (second),*Δθ:* rotation value of front wheel (degree), *R:* dynamic radius of front wheel (meter).

Δt is measured and registered by information collector unit. This value is obtained by subtracting current registration time from previous time. Usually this value is constant and equal to the rate of collecting information. For example, if information to be collected two times in every second, this time is equal to 0.5 second. In addition, R is approximately a constant value for every tractor. $\Delta\theta$ is obtained by the system of angle gauge. The radius of the front wheel of John Deere3140 tractor (R) is $39_{c.m.}$

According to this data, the following equation is obtained to determine the motion velocity of the tractor:

$$dx = \frac{0.17578125 \times 2 \times 3.1415 \times 0.39}{360} \approx 0.0012\,(m)$$

Moreover, considering the fact that the rate of information collection is 20HZ, the minimum speed is 1m/s and the accuracy of data logger is 50KHZ, the measurement error of velocity is obtained by this equation:

$$dv = \frac{tdx - xdt}{t^2} = \frac{1}{t}(dx - vdt) = \frac{1}{0.05}\left(0.0012 - 1 \times \frac{1}{50000}\right) = 0.0236$$

That is perfectly an acceptable error (lower than 2.5%).

The system of information collection

The information obtained from circuits of strain gages and the angle of lower arm and velocity meter of its input and output parts are preserved in computer and demonstrable by a monitor.

A data logger was selected for information collection. The selected data logger for the device has sufficient channels for input information.

This device has two voltage output of electrical circuit for every lower load cells and one voltage output for the upper circuit. Therefore, we need five analog channels for the data logger. In addition, the angle gauge has 5 outputs and the velocity meter has 11, so 16 input digital channels are needed. The velocity of information collection was considered to be 20HZ.

For this dynamometer, SDA-810C data logger was selected which is the product of Japan TML Company. In addition to mentioned abilities, this data logger has special software that can be programmed by a computer. Also, it has a monitor which presents diagrams and figures concurrently.

This data logger can actuate the circuits of strain gage. The actuating voltage of all available circuits in dynamometer is 5V. This data logger is fed by a tractor battery. In the software of data logger, inputs are received, and equations obtained at previous sections are given to it to compute tension and vertical force and tension power. Thus the concerned parameters are obtained. Also in this way, the raw data can be transferred to the computer and through it to carry out necessary programming.

Conclusion:

The dynamotors designed and constructed inside the country has been of the frame type so far. The frame dynamometers have not been able to meet the needs of country because of its complicated design, difficult construction and errors which they have. Therefore, efforts was made to design a linking dynamometer suitable for the situation of country such that in the construction materials and all other necessary items, the products available in the country to be chosen and used. Most of research and commercial dynamometers designed so far have fewer abilities as compared with the above-mentioned designed dynamometer. Most of the dynamometers can only measure the tension force and cannot compute the vertical force. In most of the other dynamometers, arms angle is not measured and it should be measured at first and not to change during the operation, but it occurs inevitably and consequently makes error. In most of the dynamometers, the measurement of instantaneous velocity has been given up and therefore power cannot be measured. These kinds of dynamometers do not consider the very important effect of velocity on the soil resistance. During working with these dynamometers, it is supposed that the velocity to remain constant but this never happens and makes errors. However, in designing this dynamometer, efforts were made to avoid the assumptions which cause many errors. In addition, it was tried that the dynamometer to have a suitable capability and flexibility, so that measurement could be carried out with an accuracy and a suitable easiness. Arms angle is computed at every moment and changing the angle makes no error in this device. Furthermore, there will be no need to measure arms angle at the beginning of the operation. Instantaneous velocity is computed, so that there will be no need to for the velocity to remain constant during the operation. Using this dynamometer, it is possible to measure the effect of velocity on the soil resistance. In total, the construction cost of this dynamometer is forecasted to be about 1,660,000:00 Rials.

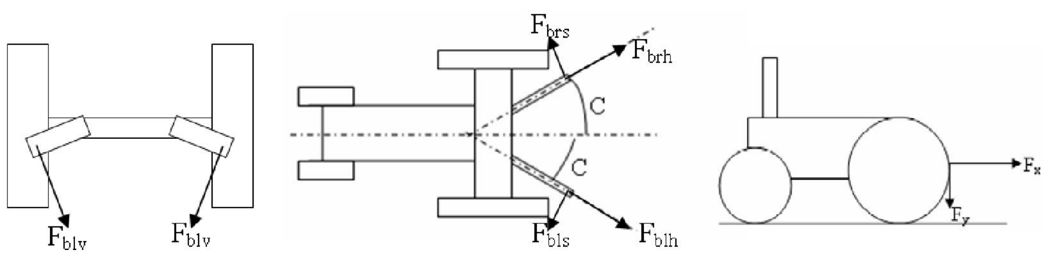

Figure1-left and right: the way of incoming forces on low arms of tractor- Right: tension and vertical forces

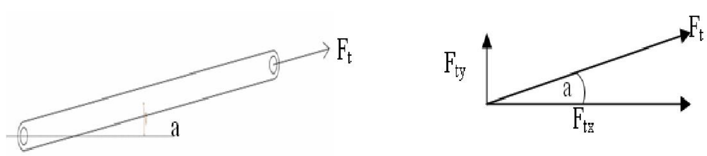

Figure2- position of forces in top arm- Left: axis force and its angle with horizontal plane (a) –right: analyzing of axis force to tension and vertical components

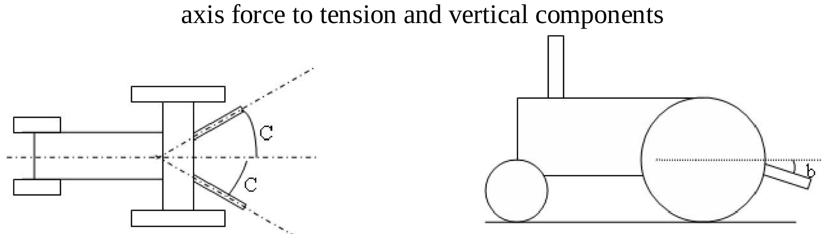

Figure 3-right: angle between the low arms and the horizon (b) –Left: angle between low arms and vertical symmetry plane of tractor(c).

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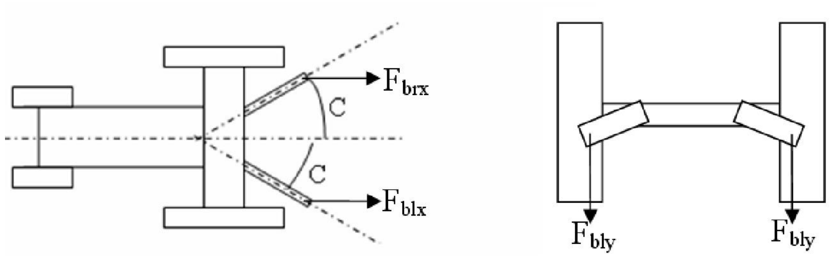

Figure 4- Introduced forces in different exponent of tractor- Right: back exponent of tractor- Left: top exponent of tractor

Figure5_right: main part of John Deere 3140 tractor's arm. Left: final part of John Deere 3140 tractor's arm.

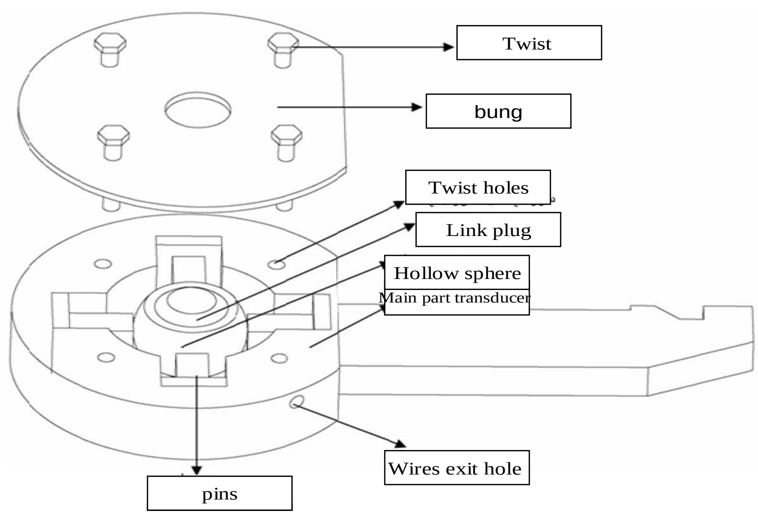

Figure 6- load cell components of low arm

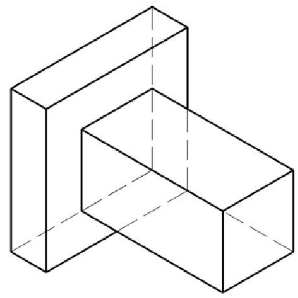

Figure7- Isometric exponent of sensor pin of low arms´ load cell force

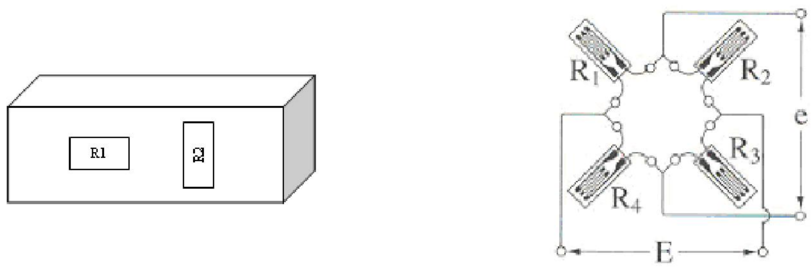

Figure8-left: locating method of strain gages on the section top arm –right: locating method of strain gages in circuit

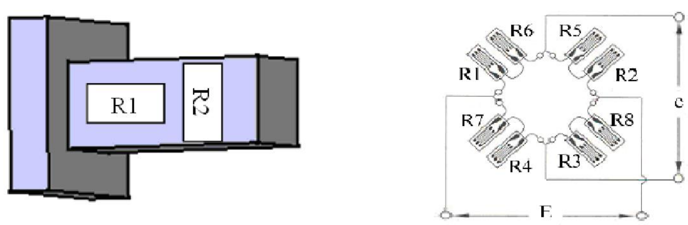

Figure9-left: locating way of strain gages on pins, which sense the load cell strain of low arm- right: arrangement way of load ell strain gages of low arm

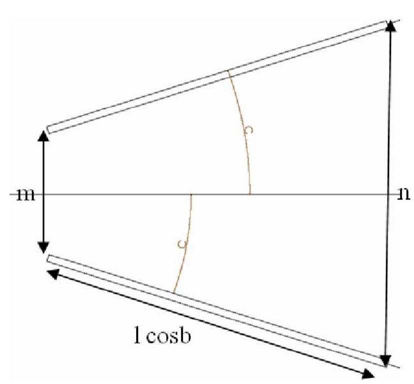

Figure10- low arms in horizontal plane

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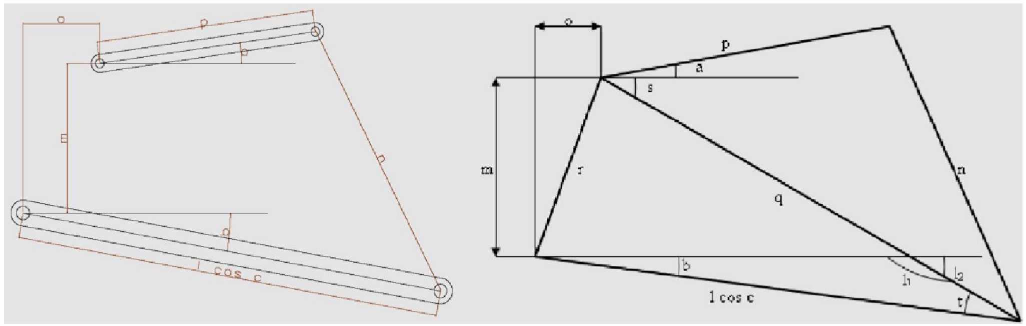

Figure11-left: top and low arms in vertical plane- right: geometrical shape for obtaining the size of angle

Suggestions

The following suggestions are made for repeated designing and manufacturing the device:

1-This device should be constructed according to the essential needs of domestic working places of agricultural implements producer and research centers, and its advantages and disadvantages to be evaluated in practice.

2-In the construction of this device, maximum accuracy should be carried out because the construction of a measurement device is very important. In the event of an inappropriate construction, the accuracy of device will severely decrease. It is recommended that its load cells to be constructed by using advanced devices like CNC.

4-Considering the fact that with the reduction of lateral force and also the angle of the lower arms with the vertical symmetry plane of tractor, the accuracy of device will increase, so it is recommended that during working with dynamometer, the increase of these two values to be prevented from.

5-During operation, the angle of the lower arms with horizontal and vertical symmetry plane of tractor should be equal.

6-If the accuracy of measurement in the upper arm is not enough, it is possible to increase it by replacing the section upon which the strain gauges are with a section of a better quality.

7-Before beginning the operation, first, the measuring system of the lower arms angle should be calibrated in different angles, then the velocity meter to be calibrated in different speeds and the transducers to be calibrated by suitable and accurate devices, too.

8- Given the high accuracy, the most useful information can be obtained by installing this device on tractors, which are equipped with accurate agricultural systems.

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