Design and Construction of Load Cell of a Three Point Hitch Dynamometer for Tractor John Deere 3140

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Abstract
Measurement of the values of forces in tractor arms is of great importance due to draft of agricultural equipment. These values can be used for testing and evaluation of the agricultural machinery, selection of suitable tractor, etc. The tools which are used for measurement of the forces are called dynamometer. The main objective of the present study was to design and evaluate a load cell for integral three point hitch John Deere 3140 tractor. These load cells are installed on the bottom links and measured draft forces. The sensitive parts of these load cells are square side pins on which some strain gages were installed and the force was measured. This load cells do not have the errors usually faced with in other load cells such as reciprocal sensitivity and hitch point movement. Besides, their manufacturing cost is very lower than the other similar load cells.

Keywords
Dynamometer, Three point hitch, Load cell, Design, Construction.

1. Introduction

Nowadays, a considerable part of energy is used for agricultural activities and their mechanization, and an enormous sum is also spent on providing the required powers of mechanization. Reports on the amount of energy consumption in the U.S 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 the tillage part that is annually applied 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 [1].

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. The size of the implements can be inconformity 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 in formation 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 [2].
A three-point hitch dynamometer is needed to measure the tension resistance between tractor and the 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 contain load cells, installed on a special frame placed between tractor and the implements. In other words, the frame is designed in such a way that it is connected to a tractor from one side and to the implements from the other side. The main advantage of the frame dynamometer is that it is not for a special kind of tractor. However, the frame dynamometers have many defects such as the following:
1-There is a need for making a special frame which is a very difficult, time consuming and costly task. As its parts are very big and heavy, on the other hand, they need a high accuracy for prevention of problems while being connected to the tractor and linking the implements to them.
2- The frame displaces the linking point of the implements to the tractor about 200-300m.mbackward. This displacement completely disorders the status of the exerted forces on tractor and makes small and large errors, depending on the displacement amount.
3- Frame weight can be over 200kg which has an important role in the 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 the PTO axis in case of the 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 the PTO axis.
Considering the need of country, advantages, and good accuracy of linking dynamometers, we designed an advanced linking dynamometer.

2. Materials and method

2.1 Selection of tractor

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 its prevailing usage and appropriate power (95horse powers). In addition, the form of its lower arms is such that it facilitates the designing of dynamometer transducers.

2.2 Analysis of force

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 indirection of tension and vertical forces, the arms angle should be determined in relation to the horizontal and vertical planes of tractor. For this reason, angle computing system was designed to specify lower links angle in the ratio of the horizontal plane.

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

2.3 Forces in the linking points of the 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 the upper arm (Ft), but in two lower hitch points, forces are in three directions: in direction of arm axis (Fblh, Fbrh),perpendicular to the arm direction (Fblh, Fbrh) and lateral (Fbrs, Fbls) (Figure1-left and middle andFigure2).

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

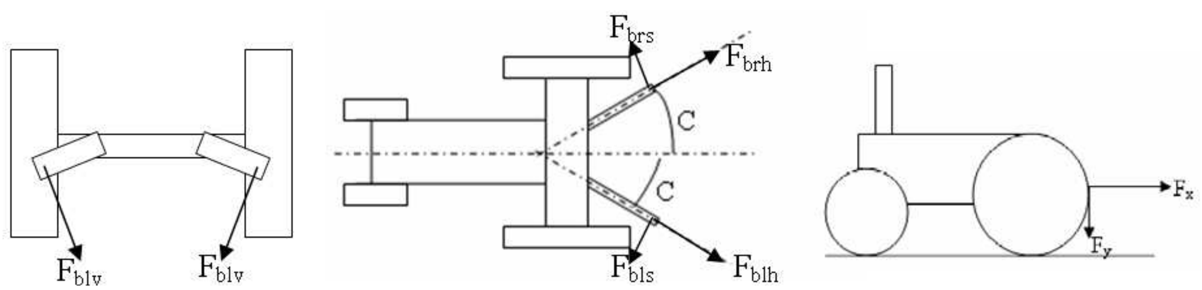


Fig.1. Left: the way of incoming forces on the low arms of tractor- Right: tension and vertical forces

Then, the tension force (Fx) can be obtained through the algebraic sum of horizontal components, and vertical force (Fy) by algebraic sum of vertical components Considering the arm angle in the ratio of the horizontal plane (a), the axis force of upper arm is analyzed to its components in the direction of tension (Ftx) and vertical (Fty) (Figure2).

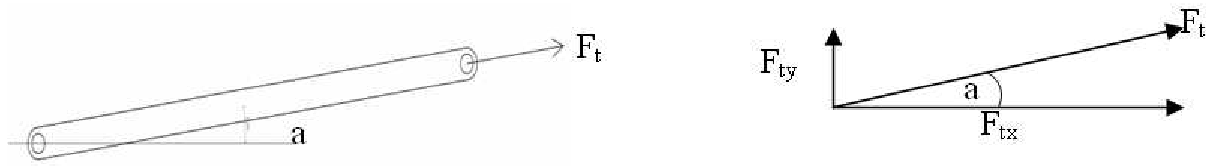


Fig.2.Position of forces in the top arm- Left: force axis and its angle with the horizontal plane (a) –Right: Analyzing of

$Ftx=Ft \, .\cos a$ (1)

$Fty=Ft \, .\sin a$ (2)

Lateral forces can be usually 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, form easuring 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 over look the lateral forces and consider the two angles presented in Figure 3.

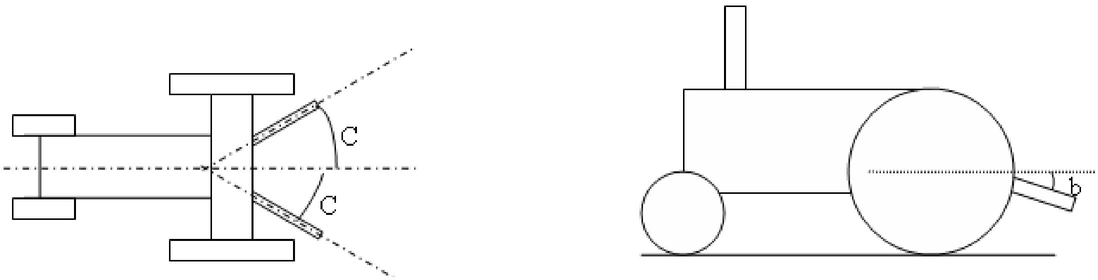


Fig.3.Right: the angle between the low arms and the horizon (b) –Left: the angle between the low arms and vertical symmetry plane of the tractor(c)

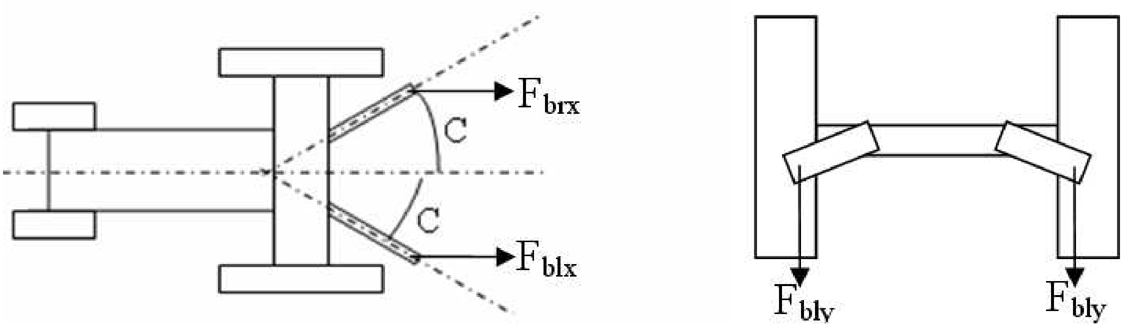


Fig.4.Introduced forces in different exponent of tractor- Right: the back exponent of tractor- Left: the top exponent of tractor

$Fblx=Fblh.\cos b \, . \cos c - Fblv. \sin b \, . \cos c$ (3)

$Fbrx=Fbrh.\cos b \, . \cos c - Fbrv. \sin b \, . \cos c$ (4)

$Fbly=Fblh.\sin b + Fblv. \cos b$ (5)

$Fbry=Fbrh.\sin b + Fbrv. \cos b$ (6)

2.4 Computation of tension and vertical forces

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

$Fx=Ftx+ Fblx+ Fbrx$ (7)

$Fy=Fty+ Fbly+ Fbry$ (8)

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

Fx=Ft .cos a + Fblh. cos b. cos c – Fblv. sin b. cos c+ Fbrh. cos b. cos c – Fbrv. sin b. cos c (9)
Also, by substituting (2), (5) and (6) equations intoequation (8), vertical force is obtained:
Fy= Ft .sin a + Fblh. sin b + Fblv. cos b + Fbrh. sin b +Fbrv. cos b (10)
Now by measuring the axis force (Fbrh, Fblh),perpendicular to axis (Fbrv, Fblv) of the lower arms and the axis force of the upper arm (Ft) and the angles of upper and lower arms (a, b and c), the values of tension and vertical force can be computed.

2.5 Design and construction of lower arms load cells

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), the load cells were designed in such a way that just the final small part of tractor had to be changed for locating the load cell. The designed load cell (Figure 6) is located in the sliding part of lower arm (Figure 5-left),instead of being locate din final part (Figure 5-right). This method is quite desirable because of its more simple construction and accuracy of device and because it does not make any problem in the 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 would not rise and the part could be constructed easily. This model was selected after designing some model for this part and analyzing the limited components of these parts inmost severe situations, and computing the weight and method of constructing. Concerning the tolerance of forces, weight and construction method, this piece is in optimal condition.


Fig.5. Right: main part of John Deere 3140 tractor arm. Left: final part of John Deere 3140 tractor arm

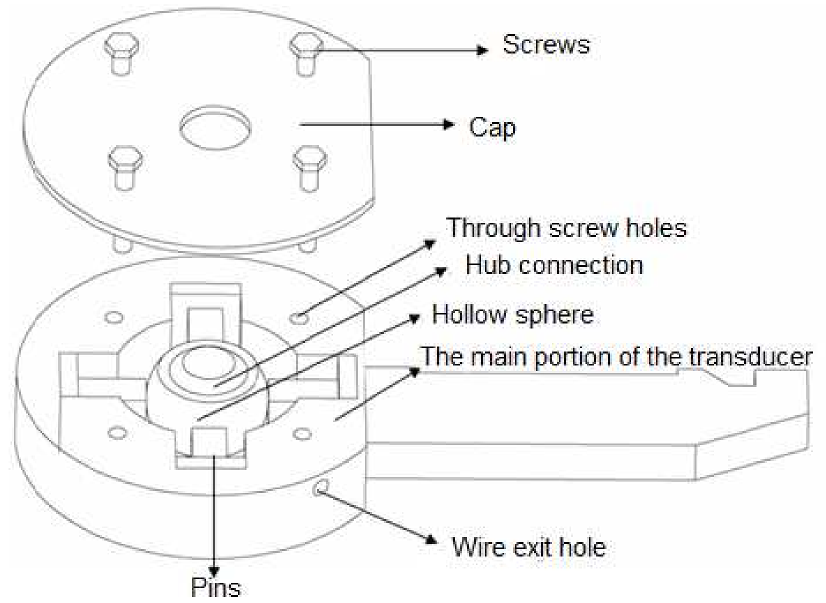


Fig.6. Load cell components of the low arm

3. Selection of software and model

CATIA V5R7 software was selected for designing and analyzing the limited components. The reason for this selection is its high ability in modeling: the designing environment of this software is much more advanced than the 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 many changes were needed to get the best form in designing of this load cell, working with other available ones 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 the needs and the 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(Figure 7). To get the best form, many models were designed and analyzed and finally this model was selected, since it can resolve the needs of our device and has suitable construction costs.

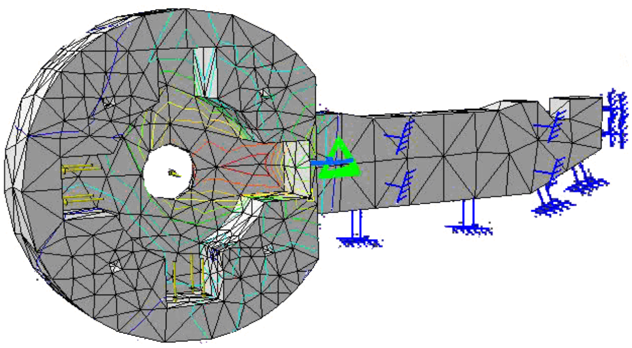


Fig.7.Stress analysis of load cells by finite element method

3.1 Construction of the load cells

Construction of dynamometer was performed in maximum precision because the construction of the measurement tool is very important and because improper construction decreases accuracy. Construction of the load cells was performed using CNC machines and steel st60 (Figure 8).

Fig.e8. Load cells

3.2 Pins

Four pins are located at the main part of the transducer to sense the force and control the hollowsphericalpart in vertical and horizontal directions.

Strain gages are installed on these four pins. There as on for selecting the square form for these parts is the accurate installation of the strain gages (Figure 9).

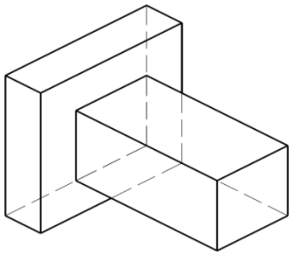


Fig. 9. Isometric exponent of the sensor pin of low arms load cell force

For designing the load cell of the lower arm,force created in this arm should be computed. Inorder to determine the maximum tension force whichis exerted on implements by the earth, a six-bottomplow was selected, every bottom with the operationwidth of 40cm and 30cm depth at 7.2 km/h speed inthe loamy soil. By this method, the maximum createdforce in both arms of tractor was 167400N andtherefore in each arm, it was 83700N.

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

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

$$A = \frac{83700}{200 \times 10^{6}} \Rightarrow A = 0.0004185\text{m}^{2}$$

Supposing that pins section is square, we have:

$$A = a^2 = 4.017 \times 10^{-4} m^2 \Rightarrow a \approx .02m = 2Cm$$

The accuracy of device can be increased by using the steels with lower elasticity modulus. One of theabilities of this dynamometer is its changeable pins.

Accuracy in measurement can be increased by the substitution of pins with smaller cross section. Ofcourse, the selected pins for load cell should have asuitable tolerance in the face of the exerted forces.

Generally, for measuring the forces of smallerimplements, we can use pins with a less cross sectionin order to increase the accuracy of measurement.

3.3 Measurement of force in the upper arm

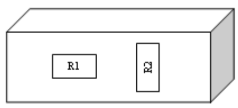
Considering the fact that in the upper arm, there exists only the axis force, measuring its forces is easier. These axis forces can be measured by installing the strain gages on the arm (Derafshi & Mardani, 2003). At the end of the upper arm of John Deere 3140 tractor, there exists a rectangular solid part which is suitable for installing the strain gages.

3.4 The selection of the strain gauge

Strain gauges were selected from Japan TML Company products because of their quality and availability. All the strain gauges of this dynamometer were selected from the FLA-10-11 kind. Considering the location of the strain gauges and the 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.

3.5 The circuits of strain gauges in the upper arm

Figure 10- Left which is a cross section of the upper arm shows the way the strain gauges are installed. In addition, two strain gauges, R3 and R4, are installed instead of R1 and R2at the front face. This kind of arrangement is used to in crease the sensitivity and eliminate the temperature effects. According to Figure 10-Right, we locate strain gauges on an electrical circuit.



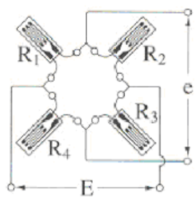


Fig.10. Left: locating method of strain gages on the section top arm –Right: locating method of strain gages on an electrical circuit

3.6 The circuit of the strain gauge in the lower arm

Two pins have been designed in the lower transducer to measure the forces in any direction. At the time of charging, one of the pins will be under pressure and the 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 11-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, such that R3 strain gauge is located

instead of R1 and R4 instead of R2. In addition, R5 in stead of R1, R6 instead of R2, R7 instead of R3 and R8instead of R4, are located on the uncharged pin.
Arrangement method of strain gages are according toFigure10-Right. This arrangement in addition to having a maximum sensitivity eliminates the effects of temperature.

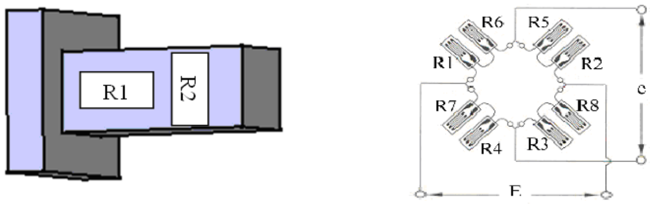


Fig.11. Left: locating way of strain gages on pins, which sense the load cell strain of low arm- Right: arrangement

3.7 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 indifferent directions.

3.8 The lower arm angle with a horizontal plane (b)
Optical sensors were selected for assigning this angle. This method has a very suitable, high accuracy of measurement in comparison with other dynamometers.
Also, it is very easy to construct. The lower arms move approximately 16 degree. For having 0.5degree of accuracy suitable for our task, we are in need of 32 statuses which are obtained by five bands(32=25).

3.9 The lower arm angle with a vertical plane(c)
We use the tractor-implements geometry to determine this angle. According to Figure12, we have:

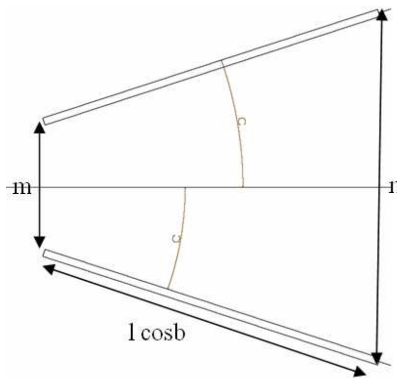


Fig.12. Low arms in horizontal plane

In Figure12, n is the gap between the two hitchpoints of tractor after linking the implements(centimeter), m=gap between two hitch points oflower arms to chassis (centimeter) and l=length oflower arm (centimeter). So angle c is obtained fromthis equation:

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

3.10 The upper arm angle with a horizontal plane (a)

Considering the geometry of tractor-implements,this angle is measurable, too. Having the informationof Figure13, we can identify the angle (a) fromgeometry of tractor-implements.

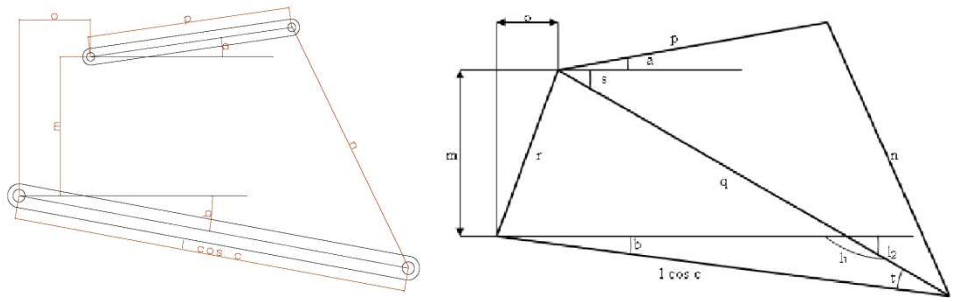


Fig.13. Left: top and low arms in vertical plane- right: geometrical shape for obtaining the size of angle

In Figure13-Right, l is the length of lower arm,m is the vertical distance of connection points of lower andupper arms to the tractor, n is the distance of the upper andlower connecting points to implements in verticalplane of tractor, o is the horizontal distance of upper andlower arms` connecting points to the tractor, and p is the lengthof the upper arm. According to Figure13-Right, wewill have:

q2 □(ṃl.cos c .sin b)2̣ (l.cos c .cos b o)2

*r*2 □*m*2̣ *o*2

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

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

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

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

$$l_2 = 180 - l_1$$

$$s = l_2$$

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

Angle (a) is computed in this manner.

4. Conclusion

The dynamotors designed and constructed in side the country have been of the frame type so far. The frame dynamometers have not been able to meet the needs of country because of their complicated design, their difficult construction and their errors.

Therefore, efforts were 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 could be chosen and used. Most of the research and commercial dynamometers designed so far have fewer abilities compared with the abovementioned 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 it should not change during the operation, but it occurs inevitably and consequently makes error. In most of the dynamometers, the measurement of in stantaneousvelocity 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, the velocity is assumed 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 accuracy and suitable ease. 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 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.

5.References

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