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STEERING EVALUATION OF TRACTOR USING THE RESPONSE SURFACE METHODOLOGY

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ABSTRACT

The research aim is to developed the traditional tractor steering system and how to choice and design the hydraulic steering of the tractor using local material and how to the steering components such as pump, steering unit, custom steering shaft, cylinder, double-shear clevis ends for the cylinder and rod are compatible with each other. On the basis of the tractor IMT (26.1kW) the hydraulic steering is conducted and the lab and field experiments are carried out. The theoretical calculated is don and the experiments are recognized in the Tractor and Machinery Testing Station at Alexandria, Agricultural Engineering Researches Institute, Agricultural Researches Center, El-Dokki – El-Giza, Egypt. From the experiments the actual outer front wheels steering angles "?o" increased with the inner steering angles "?i". It varied from about (0.0 to 35.69 degrees) at values of (?i) varying from about "0.0 to 50 degrees" respectively. The turning radius (R) increased with the increasing of inner and outer front wheel steering angles (?o & ?i). The Values of turning radius(R) varied from about [151.4 cm to 5154.5 cm] at values of (?i) varying from about [(0.0 to 50) degrees] and (?o) varied from about [(0.0 to 35.69) degrees] respectively.

INTRODUCTION

In most of the developing countries, the tractors and implements used are usually imported. The proper selection of tractor and implement for a particular farm situation requires availability of the field performance data of both tractors and implements. The tractor is not much use if it cannot be steered or guided. The act of guiding the tractor is called steering. Wheeled tractors are steered by aiming or pointing the wheels in the direction want to go.

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There is several alignment geometry angles which relate to the steering linkages that will influence the easiness with which the tractor can be steered, the steering stability and the tire wear.

The first one is the caster angle. It is the tilt of the steering axis of each front wheel as viewed from the side of the vehicle and it is measured in degrees of an angle **(Layne, 2002)**. As shown in figure (1), the caster angles a directional control geometry angle that helps keep the tractor moving straight ahead.

Finally, the third is toe angle. It is the difference in length of each axle from each other, the front to the rear wheels in straight ahead position. Toe is measured at the center of the wheels from one wheel rim to the other. **(Layne, 2002)**.Toe in is when the displacement is greater at the rear wheels and it is called toe out when the distance is greater at the front of the wheels.

Dooner (2001) suggested an eight-link mechanism incorporating optimized noncircular gear elements for the purpose of synthesizing a mechanism capable of generating functional relation for coordinated steering of automobiles. **Fahey and Huston (1997)** used an eight-member mechanism alternative to an Ackermann-type steering linkage which has seven precision points and a very small structural error in an extended range of motion. **Pramanik (2002)** proposed an six-member mechanism which has five precision points and gives fairly accurate result that between a four-bar Ackermann steering mechanism and an eight-member mechanism. **Simionescu and Smith (2002)** also used parameter design charts with four parameters to optimize the steering errors of the central-lever steering mechanism of a vehicle. **Habibi et al. (2008)** used the genetic algorithm method to optimize the roll steer of a front McPherson suspension system. The roll steer steering angle of the steered wheels during the rolling action was defined as undesirable and uncontrollable changes in the of the vehicle body due to cornering maneuver or asymmetric bumps. In conjunction with the study of three-dimensional kinematic model of McPherson mechanism. **Hanzaki et al., (2009)** presented the sensitivity analysis of rack-and-pinion steering linkage to predict how the steering error is affected by manufacturing tolerances, assembly errors, and clearances resulting from wear.

Simionescu et al. (2011) developed a kinematic model of an RRSRR-type steering mechanism suitable for rigid-axle vehicles, on the basis of which the major features of the mechanism is investigated, e.g. sensitivity to geometry changes, steering errors induced by axle displacement, motion and for force transmission functions. **Simionescu and Talpasanu (2007)** studied the problem of synthesizing the Ackermann linkage and the steering control mechanism of an adjustable tread-width tractor. Several conflicting requirements were simultaneously considered as follows: ensuring minimum wheel-slip and symmetric steering control for left and right turns, ensuring minimum cross-coupling between steering and axle oscillation, maintaining favorable pressure angles in the joints, and avoiding interference between the moving parts of the mechanism and between these and the body of the vehicle. **Mantaras et al. (2004)** presented a three-dimensional model of the kinematics behavior of a McPherson-type steering suspension. A general approach was put forward to determine the main parameters (caster, camber, steer angle, etc.) which influence the handling of the Vehicle, in function of the operational factors of the system. **Simionescu et al. (2007)** analyzed the steering system of a compact wheeled tractor using commercial multi-body simulation software. The effect of axle-oscillation induced steering errors and of the axle impacting the bump stops attached to the tractor body is compared for two design variants. It is shown that by diminishing the kinematic cross-coupling between the steering-control linkage and the axle oscillation, a favorable reduction of the dynamic loads in the steering mechanism components can be obtained for normal operation conditions of the vehicle In addition, leaf springs have been widely used in the suspensions of trucks for many years, and form a relatively simple, robust, and cheap suspension system when coupled to a beam axle. A typical construction may consist of multiple parabolic leaves in parallel, formed into a curve in their unloaded state. These may then be anchored to the vehicle chassis at their front end via a simple pin joint, and at their other end via a double-pinned support arm that accommodates the changes in spring length as the latter deflects.

Jayakumar et al. (2005) presented a simple and accurate Three-Link Leaf-Spring model with SAE guidelines. **Sugiyama et al. (2006)** developed a nonlinear elastic model of leaf springs based on the absolute nodal coordinate formulation. **Hoyle (2004)** investigated the suspension characteristics of a 10 ton truck with a highly non-linear leaf spring. Also, **Hoyle (2007)** investigated a truck with leaf-spring suspension configuration for bump steer. The beam axle will normally be attached to the mid-point of these leaves, and will inevitably move forwards and backwards as the axle moves up and down. If a longitudinal steering drag link is attached to the stub axle with the steering box directly in front of it, 'bump steer' is likely to lead to excessive suspension deflections. With the increasing use of heavy-duty trucks that have double-axle steering mechanisms, the study on double-axle steering mechanisms becomes more and more important. At present, the study and analysis of multi-axle steering system of heavy-duty vehicle is seldom found. **Watanabe et al. (2007)** introduced a mathematical model for multi-axle vehicles in terms of turning characteristics and maneuverability performance. Their results indicate that rear steering has a great effect on the turning characteristics while the position of the steering center has little effect on the turning radius.

This paper is determined to fail full the following points:-

1- Developing the traditional tractor steering system by adding the hydraulic steering of the tractor using local material
2- Design the steering components parts to compatible with each other.
3- Introduces a body model for the hydraulic steering mechanism.
4- Finally a conclusion is obtained.

MATERIALS AND METHODS

On the basis of the tractor IMT (26.1kW) the hydraulic steering is conducted and the lab and field experiments are carried out. Under the experiments the tractor specification is shown at table (1).

System design

The hydraulic system design was carried out using the following ladder:-

1-Calculate total Kingpin torque required to steer axle (kg.cm), Eaton (2003). As shown in figure 3 the total torques may be equal,

$$T = W \cdot f\sqrt{\frac{B^2}{8} + E^2}$$

Where:- T = Total Kingpin Torque required to steer axle (kg.cm)

W = Tractor weight supported by the steered axle (kg).

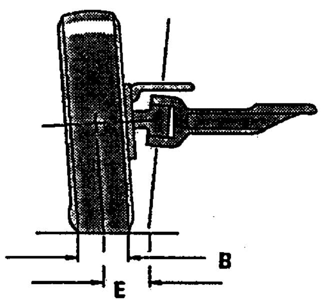
f = Coefficient of friction

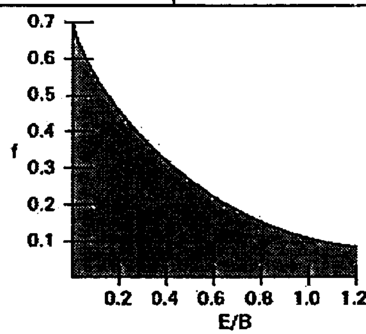
B = Nominal width of the tire print (cm)

E = Kingpin eccentric (cm).

Table (1): tractor specification

Make:	IMT	**Front tire:**	5.00-16
Model:	533	**Rear tire:**	11.2-28
Years Made:	1961 – 1988	**Wheelbase:**	72.4 inches [183 cm]
IMT 533 Engine:	3-cyl diesel	**Weight:**	3,343 lbs [1516 kg]
Engine:	35 hp [26.1 kW]	**Length:**	116.9 inches [296 cm]
Fuel:	diesel	Height:	53.9 inches [136 cm]
Bore/Stroke:	3.50x5.00 inches [89 x 127 mm]	2WD turn radius:	19.8 feet [6.0 m]
Rear RPM:	540	Cylinders:	3
Displacement:	144.0 ci [2.4 L]	Cooling:	Air
Transmission:	gear	Width:	
Gears:	6 forward and 2 reverse	Rated RPMs:	2000
Steering:	mechanical		





E = Kingpin Eccentric (offset) (cm); Typical values based on rubber tired

B = Nominal width of the tire print (cm); tractor on dry concrete

Figure (3): Measuring tire and calculate the coefficient of friction (f).

2- Calculate the required force of the hydraulic cylinder (F, kg) using the Eaton's equation (2003).

$$F = T/r$$

Where: F = Force required from the cylinder (N)

T = Kingpin torque (accounting for drive factor).

r = Effective radius arm about the kingpin axis at which the cylinder force is applied. The effective radius is the minimum distance from kingpin to the axis of the cylinder.

3- Calculate the required cylinder area for the system to generate the required force (A, sq. cm.)

$$A = F/P$$

Where: A = required cylinder area (sq cm)

P = pressure (Kg/cm^2)

4- Calculate the required cylinder for diameter (D, cm).As shown in figure (4) the (D) may be equal:-

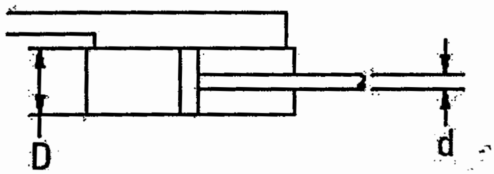


Figure (4): cylinder bore diameter

$$D = \sqrt{\frac{4A}{\pi} + d^2}$$

$$\text{Note: } \left(\frac{d}{D}\right)^2 \leq .15$$

Where:- D = Inside diameter of cylinder.

d = shaft diameter

Once the required cylinder set the area is determined. Also, once D is calculated, mathematically, select the next larger common cylinder bore size available.

5- Determine the required cylinder stroke (S, cm)

The cylinder stroke is determined by axle geometry. That is, the required stroke is a function of the radius arm (steering arm) and the total angle through which the arm turns. An easy way to calculate it requires at least some kind of temporary fixed toe rod between the steered wheels. With this in place, turn the wheels by hand to full left turn. Make an indexing mark on the axle housing and the tie rod in the same place. Now turn the wheels to full right lock and measure the difference between the marks. This measurement is your stroke (S).

6- Calculate the swept volume (V) of the cylinder(s) from the following equation:-

$$V = S \times \frac{\pi}{4} \times D^2$$

Note that a single unbalanced (differential) cylinder will have a large volume (called the head end volume) and a small volume (called the rod end volume)

7- Decide on the approximate number of turns lock-to-lock desired. This number will vary - usually from about 2 to 6.

8- Calculate the required displacement of the steering unit per revolution in order to achieve the desired turn's lock-to-lock (DP, cu. cm/rev) that;

$$DP = V/N$$

Where: V = Swept Volume of full stroke from step 10 (cu cm).
N = number of steering wheel revolutions lock to lock
DP = actual displacement of steering unit (cu cm/ rev)

9- Select steering unit from those available, note actual displacement, and re-calculate actual number of turn's lock-to-lock from the equation as follows:-

$$N = V/DP$$

Again, note that this figure will differ between left to right is a single unbalanced cylinder is used.

10- Determine maximum required steering input speed (SS, rev/ sec)

11- Calculate required pump flow (QP, cm^3 per minute) from the following equation:-

$$QP = (SS \times DP \times 60) / 1000$$

Where: QP = required flow of pump (cm^3 per minute)
SS = steering speed (rev/ sec)

The tractor steering modifying

The following steps are carried out to modify the tractor steering:-

1- At first, the mechanical steering system was removed. Then began to put new hydraulic system with the wheel spindle and spindle bushing. A small plate with (5 x 6 x1cm) was welded in the middle of the wheel spindle to put the tie end rod. Then put the tie rod ends. After then the Ackermann arms connected to transfer steering force to the slave spindle. They are adjustable to allow for toe setting, to reduce tire wear and control wander. The assemblies of cross tube are made up of two tie rod ends, tube and clamps.

2- Then Mini tie rods have to be constructed to connect the ends of the cylinders shafts to the wheel spindle. The stroke of the piston is 25 cm so the half of the stroke (12.5 cm) was used out to pull the wheel spindle to turn left and the other half of the piston used to push the wheel spindle to turn right.

3- The rectangular iron shape (20 × 40 cm) fixed at the Radius Rod with two bolts to carry the reservoir 9-the important part of the system is the pump and to put the pump on the operate system .it is very difficult part of the system ,at first the source of the power to operate the pump is the important thing ,so there is a pulley(14 cm diameter) put on the pulley used to operate the dynamo as the source of the power to the pump as shown in figures (6) Then put the pump with the second pulley (9 cm diameter) on the other side of the first pulley and it must be parallel to the first pulley ,so the T steel shape as shown in the picture used to carry the pump as shown in figures (6) and the metal plate with (12 × 18 × 1 cm)with four holes to construct the pump with 4 pivot number (13) and the plate has two port used to increase or decrease the distance between two pulley as shown in figures (6)after that put the v belt (v-belt -13 × 1025- A 40) and put the two steel flanges. At The end put the small plate to fix the pump as shown in figures (6).

Figure (6): construct the pump.

4- So there was a plate used to confirm the steering unit on the tractor. The plate was used have four holes to fix on the tractor. Connect the steering column to the steering unit and they connect to steering wheel, hoses and the fitting on the hydraulic tractor steering and put oil in the reservoir and bleeding the system then the tractor is ready to drive as shown in figures (7).

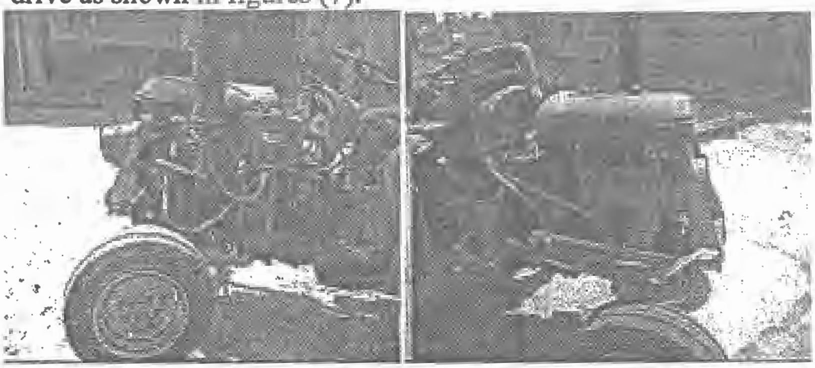


Figure (7): the tractor ready to use

Referring to the figures 8 and 9 the steering angle may be calculated regarding to the general equations as:-

$$\theta o = \tan^{-1}\frac{B}{R+L/2} \qquad \theta i = \tan^{-1}\frac{B}{R-L/2} \qquad \frac{1}{\tan\theta o}-\frac{1}{\tan\theta i}=\frac{L}{B}$$

Where: ?o= turn angle of the wheel on the outside of the turn

?i= turn angle of the wheel on the inside of the turn

L = track width

B = wheel base

b= distance from rear axle to centre of mass

From the above equation and assuming B =1830 mm, L =1320 mm and ?i =30° and then ?o = 22.12° Also, the minimum radius of turn "R" can be determined from the geometry:

$$R1 = \frac{B}{\tan \theta i} + \frac{L}{2} = \frac{1800}{\tan 30} + \frac{1320}{2} = 3778mm = 3.7m$$

$$R = \sqrt{R1^2 + b^2} = \sqrt{3778^2 + 800^2} = 3862mm = 3.86m$$

Therefore the minimum radius of turn of the vehicle around its centre of gravity for a maximum inside wheel turn of 30 degrees is about 4 meters.

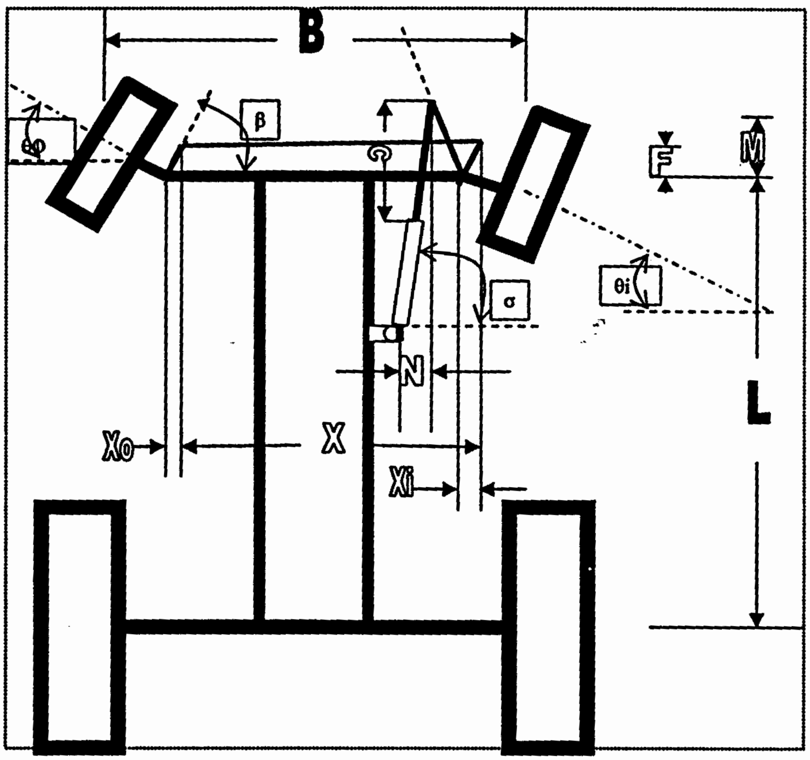


Figure (8): The lateral translation produced by the steering is relayed through the linkages to steering arms on the left and right front wheels.

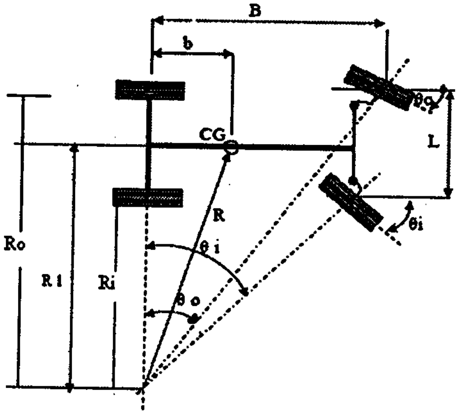


Figure (9): Ackermann condition

RESULTS AND DISCUSSIONS

The steering calculation

The tractor hydraulic steering component was calculated as shown in the system design. The results shown in table (2)

Table (2) show calculation of tractor hydraulic steering

Step 1 - Calculate approximate Kingpin Torque (kg.cm)		
Weight on steered axle (kg)	W	508
Coefficient of friction	f	0.28
Nominal Tire Width (cm)	B	12.7
Kingpin offset at ground intersection (cm)	E	6
Drive factor (2 if steered wheels are driven 3 if hubs are locked / diff is locked or spooled)	d	3
Kingpin Torque (kg .cm)	KT	3197.87
Step 2 - Calculate Approximate cylinder force		
Minimum Radius Arm (cm)	R	6
Cylinder Force (kg)	F	533
Step 3 - Determine pressure rating of system		
Pressure rating of pump (bar)	P	200
Step 4 - Calculate required Cylinder Area (sq. cm.)		
Cylinder Area (sq. cm.)	CA	2.665
Step 5 - Determine style of cylinder used		
Style	y	2
1=single balanced		
2=single unbalanced		

3=cross connected unbalanced

there is no cylinder with 1.2 cm diameter. So we must take the cylinder diameter 2.85cm

Step 6 - Determine diameter of shaft (rod) of cylinder(s)		
Shaft diameter (cm)	Sd	2.85
Step 7 - Determine required cylinder stroke (cm)		
Cylinder Stroke (cm)	S	20.32
Step 8 - Calculate approx required Cylinder Bore (cm)		
Cylinder Bore (cm)	CB	3.07
Step 9 - Calculate Swept Volume of Cylinder(s) (cu. cm)		
bore diameter (cm)	b	5
rod diameter (cm)	r	2.85
Cylinder Stroke (cm)	S	20.32
SV=(pi/4)(b^2-r^2)S		
Swept Volume (cm^3)	SV	269.353
Step 10 - calculate required steering unit		
number of turns lock-lock	n	3
Valve displacement required (cm^3)	HD	89.784
Step 11 - Determine displacement of nearest steering unit		
	HD(act)	97.33
Step 12 - calculate turns from lock to lock		
number of turns lock to lock	n	2.7674
Step 13 - calculate minimum pump flow (cm^3 per minute)		
Displacement of actual valve (cu. cm./rev)	HD(act)	97.33
Fastest Steering Speed required (rev/sec)	SS	2
Minimum Pump Flow Required (cm^3 per minute)	Q	11680
Minimum Pump Flow Required (liter per minute)	Q	11.68

N.B.: Bold red values are entered by user, Blue values are calculated

Effect of the inner front wheels steering angles on the outer steering angles:

Figure (10) shows the relation ship between The actual and theoretical outer front wheels steering angles (?o actual & ?o theoretical) with the inner steering angles (?i).The actual and theoretical outer front wheels steering angles (?o actual & ?o theoretical) increased with the inner front wheel steering angles (?i). Values of (?o actual) varied from about [(0.0 to 35.69) degrees] higher than values of (?o theoretical) varied from about

[(0.0 to 33.93) degrees] at values of (?i) varying from about 0.0 to 50 degrees respectively.

Figure (11) shows the actual outer front wheels steering angles (?o actual) increased with theoretical outer front wheels steering angles (?o theoretical). Values of (?o) actual varied from about [(0.0 to 35.69) degrees] higher than values of (?o) theoretical varied from about [(0.0 to 33.93) degrees]. The relation ship between (?o actual & ?o theoretical) can be calculate with $y = 3E\text{-}05x^3 - 0.0031x^2 + 1.023x - 0.0429$ with $R^2 = 0.9999$.

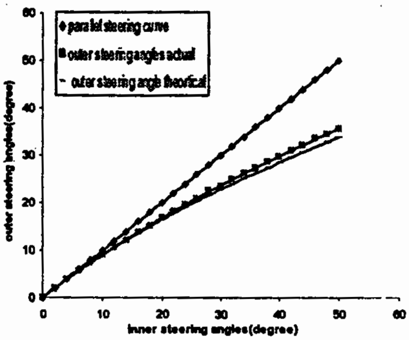


Figure (10): The relationship between the actual and theoretical outer front wheels steering angles with the inner steering angles.

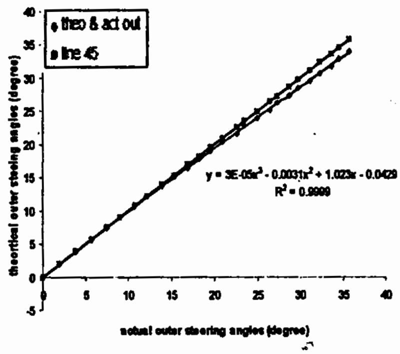


Figure (11): relation ship between actual and theoretical steering angles.

Effect of the turning radius on inner and outer steering angles

Figure (12) shows the Relation ship between the turning radius(R) with actual inner and outer steering angles (?o actual & ?i actual). The turning radius (R) increased with the actual inner and outer front wheel steering angles (?o actual & ?i actual). The Values of turning radius(R) varied from about [151.4 cm to 5154.5 cm] at values of (?i) varying from about [(0.0 to 50) degrees] and (?o actual) varied from about [(0.0 to 35.69) degrees] respectively

Figure (13) shows the Relation ship between the turning radius(R) with theoretical outer and inner steering angles (?o theoretical & ?i). The turning radius (R) increased with the theoretical outer and inner front wheel steering angles (?o theoretical & ?i). The Values of turning radius(R) varied from about [(151.4 cm to 5154.5) cm] at values of (?i) varying from about [(0.0 to 50) degrees] and (?o theoretical) varied from about [(0.0 to 33.93) degrees] respectively.

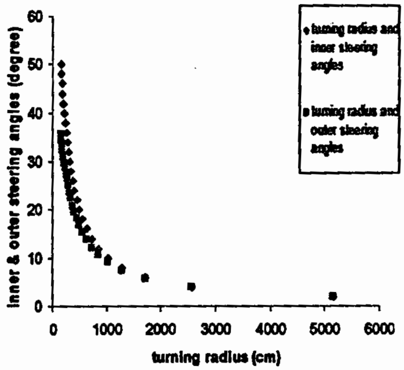


Figure (12): Relation ship between turning radius and actual outer and inner steering angles.

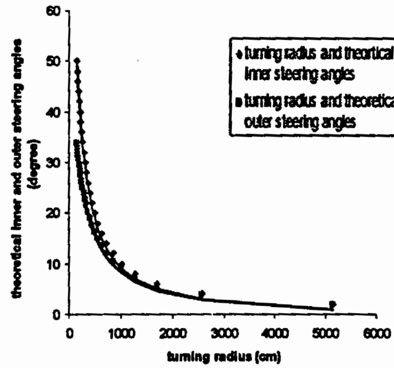


Figure (13): Relation ship between turning radius and theoretical outer and inner steering angles.

CONCLUSION

From the experiments the actual and theoretical outer front wheels steering angles (?o actual & ?o theoretical) increased with the inner front wheel steering angles (?i). Values of (?o actual) varied from about [(0.0 to 35.69) degrees] higher than values of (?o theoretical) varied from about [(0.0 to 33.93) degrees] at values of (?i) varying from about 0.0 to 50 degrees respectively.

The turning radius (R) increased with the actual inner and outer front wheel steering angles (?o actual & ?i actual). The Values of turning radius(R) varied from about [151.4 cm to 5154.5 cm] at values of (?i) varying from about [(0.0 to 50) degrees] and (?o actual) varied from about [(0.0 to 35.69) degrees] respectively.

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الملخص العربى

تقييم أداء التوجيه للجرار باستخدام اقل استجابة سطحيه لاختلاف المعاملات

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نظرا لان معظم الجرارات التى تستخدم فى مصر تستخدم نظام التوجية الميكانيكى مما يؤدى الى صعوبة التوجية واضافة مجهود كبير على السائق اثناء عملية التوجية للتغلب على عدم انتظام الارض اثناء اعداد التربة وتجهيزها للزراعة. ونجد ان التوجية فى الجرارات من العوامل المؤثرة جدا فى عمليات اعداد التربة وخاصة فى الزراعة الدقيقة حيث ان التوجية الميكانيكى الغير جيد يؤدى الى عدم انتظام الزراعه وكذلك عدم انتظام الخطوط وبالتالى عدم انتظام توزيع النباتات ويعيق من عمليات خدمة المحصول ويزيد الفاقد من النباتات اثناء عمليات الخدمة المختلفة بعد عملية الزراعة وخاصة فى النباتات التى تحتاج الى عمليات العزيق.

وخلال البحث يتم استخدام جراران زراعيان من نفس النوع والموديل (IMT) وبنفس الكفاءة ويتم عمل تعديل لنظام التوجية للجرار الاول ليستخدم نظام التوجية الهيدروليكى بدلا من نظام التوجية الميكانيكى والجرار الاخر يستخدم نظام التوجية الميكانيكى. تم هذا فى محطة ابحاث و اختبارات الجرارات والالات الزراعية التابعه لمعهد بحوث الهندسة الزراعية بالصباحية – الاسكندرية. تم عمل برنامج يمكن من خلالة حساب الاجزاء الخاصة بجهاز التوجية عن طريق ادخال بعض البيانات الملحقة بكتالوج الجرار.

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ومن خلال ذلك يمكن بسهولة جدا تجميع وتركيب جهاز التوجية الهيدروليكى الخاص بالجرار مع توضيح خطوات تركيب الاجزاء المستخدمة لمعرفة كيفية عملها بالاضافة الى وجود شرح تفصيلى للخطوات الرئيسية التى يمكن من خلالها تركيب جهاز التوجية الهيدروليكى. وكذلك هناك شرح تفصيللى لكيفية معرفة الخطوات التى تمت من خلالها استخدام المعادلات الخاصة بالحسابات ابتداء من تغيير جهاز التوجيـة الميكانيكى وحتـى تركيب جهاز التوجيـة الهيدروليكى.وقد وجد من التجارب المبدئية ان زوايا التوجية الخارجى تتزايد قيمتها مع زوايا التوجية الداخلى حيث كانت تتراوح قيم زوايا التوجية الداخلى من(٠,٠ حتى ٥٠ درجة) مع قيم زوايا التوجية الخارجى الفعلية من (٠,٠ حتى ٣٥,٦٩ درجة) و مع قيم زوايا التوجية الخارجى النظرية من (٠,٠ حتى ٣٣,٩٣ درجة). كما وجد ان نصف قطر الدوران يتزايد قيمتة مع قيم زوايا التوجية الداخلى ومع قيم زوايا التوجية الخارجى الفعلية والنظرية حيث كانت تتراوح قيم نصف قطرالدوران من (١٥١,٤ حتى ٥١٥٤,٥ سم) مع قيم زوايا التوجية الداخلى من (٠,٠ حتى ٥٠ درجة) مع قيم زوايا التوجية الخارجى الفعلية من (٠,٠ حتى ٣٥,٦٩ درجة) ومع قيم زوايا التوجية الخارجى النظرية من (٠,٠ حتى ٣٣,٩٣ درجة) بالترتيب.