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DEVELOPMENT OF POWER TRANSMISSION SYSTEM FOR WATERING MACHINES

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ABSTRAC

An investigation was carried out to develop a unit of power transmission system for facilitating starting up of watering machines. This unit is used to transmit power after starting the engine and then loading power to other attached member. Three parameters included shaft speed (350, 600, 850 and 1200 rev./min), contact area (100, 150 and 200 cm^2) and contacting material (rubber, linen or coarse surface) were tested. The percentage of slip, efficiency of mechanical transferring (contacting efficiency), fuel consumption, power and energy requirements were measured. Total cost was estimated according to the recent prices. The results showed that increasing shaft speed to 1200 rev/min with 200 cm^2 linen contacting material resulted in increasing contacting efficiency 99.95 % and fuel consumption 2.3 l/h and power and energy requirements of 6.35 kW and 0.42 kW.m^3/h, respectively, while decreasing slip percentage to 0.05%. Total costs of fabricating and installing the developed unit were assumed according to the recent market price and were found to be 500 LE. Generally, it is advisable to produce the developed unit in a large scale and install in all watering machines to facilitate and lessen the performance hazards.

INTRODUCTION

Many problems face the manufacturer and, or operator while operating the watering system, such as a suitable method for transferring power between the power source to watering implement which are available and usual using under Egyptian conditions as pumps, waterwheels or mechanical Archimedean screws. These problems can be totalized around safety using, less costs, little components and simple operating. Most of watering machines face many problems such as the loading producing on bearings as reaction of tension of flat belts, which causes continually damages for them especially with waterwheels machine and mechanical Archimedean screw types. Another problem which relates by transferring flat belt -the free origin-influencing on safety factor that one belt position -in operated space- and its instructed state, normally or reversely (shear position) which mostly needed while operating mechanical Archimedean screws. Most important problem that difficulty of starting the engine that because of load presenting on attaches origin-such as bearings, flat belt, pulleys, gears and shafts- with engine shaft.

Sergio Mottura, (2000) structured a roller blind comprising a horizontal roller for supporting the blind and the mounted for rotation about its own axis, a blind having an upper edge, resilient means tending to bias the roller towards a position in which the blind is rolled up, and a centrifugal mass brake for slowing the rotation of the roller during rolling up of the blind. The centrifugal-mass brake is carried by a fixed support structure outside the roller and the rotor of the brakes is connected to the roller through the interposition of step-up wheels and a one-way clutch device adapted to break the connection between the rotor of the brake and the roller when the blind is lowered, the one-way clutch device and the step-up wheels also being carried by the fixed support structure, outside the roller.

Tomas A. Genise (2003) stated that centrifugally operated friction clutches are well known in the prior art and typically include a driving input member driving by a prime mover, usually an electric motor or internal combustion engine, and weight rotatable with the driving member which, upon rotation of the driving member, will move radials outwardly under the effect of centrifugal force to cause the driving input member to frictionally engaged a driven output member. Wasif *et al*. (2006) mentioned that the highest discharge rate, lowest power consumption and best conditions were noticed at screw top diameter equal 1.5 bottom diameter and impeller fixed on distance equal bottom radius inside the screw with 2.0 mm impeller clearance under impeller speed about 500 to 600 rpm. Shrein et al. (2007) studied the effect of waterwheel transmission system by adding gearbox instead of the traditional system which decreased the consumed energy and saving the operational costs comparing to traditional waterwheel transmission system. WanNik (2012) investigated that the commercial friction materials normally contain mainly alumina ($A1_2O_3$) and other ingredients. It appeared that an overall friction coefficient value declined with the increase in drum temperature.

Many methods are used to transmit power in operating watering machines, that one by putting the flat rubber belt on flatted pulley fixed on engine shaft to transmit the rotating moving to other pulley of waterwheel or mechanical Archimedean screw, that method caused difficulty engine starting, so, it may needed to un-assemble the belt and re-assembling it after operating the engine. That way causes a severity to the operator and causes damage to belt which be replaced soon after little period. Another way is by instructing two flat pulleys instead of one in prolongation engine shaft, one of these two pulleys is fixed and the other is free. To operate the engine, the belt is putting on the free one, after operating, the belt is pushing manually to the fixed one. A third method is by instructing a gearbox unit instead of the transferring system (belt, pulleys, gears and shafts) and using a stronger engine with a clutch. That method is more safety but more costs. Generally, the main objective of this study is to investigate the suitable characteristics performance of the developed unit for transferring power between the power source (engine or motor) to watering implement (pump, water wheel or mechanical Archimedean screw) which are available and usual using under Egyptian conditions.

MATERIALS AND METHODS

The investigation is worry by the most and familiar problems, which is the difficulty of starting the engine with less costs and high efficiency by make a simple modified power attachment unit fixed to watering machine which are spread all over Egypt governorates. Therefore, this investigation is carried out to develop the conventional power transferring system without replacing the whole parts with less costs, more safety, less wearing of its parts with high efficiency and in order to avoid replacing whole power transferring system especially flat belts.

A scope of the study and unit:

The unit was designed in order to transmit the rotated power of the engine to the pump which raised or moved water. These components can be totalized as a disk (Fig 1) carried two masses, like a shoe (which are installed on a centric disc fixed on the flywheel of engine) with free movement in perpendicular to the circumference area to a bottom cylinder face (Fig 2) (which is installed on propagation to engine shaft). A flat belt is used for transferring the engine power to the pump, waterwheel or mechanical Archimedean screw (Fig 3). After many hours of operating, coarse contacting area of shoe was more erosion, so it needed to be replaced.

Water head in the mechanical Archimedean screw of 150 cm was selected under all treatments, as controlled condition. The mechanical Archimedean screw characteristics are shown on Fig 4 and the developed unit characteristics are summarized in Table 1.

Table 1: The unit characteristics:

Item	Characteristics
Disc diameter and thickness, cm;	42 and 1, respectively
Bottom surface of driven cylinder dia., cm;	40
Circle of shoes dia., cm;	39
Weight of each shoe, kg;	5
Thickness of fractional material, cm;	0.5
Effective length of fractional arc on shoe, cm;	20
Effective width of fractional arc on shoe, cm;	5
Carrier shaft and flatted pulley dia., cm;	5 and 15, respect.
Spring dia., length, cm,; ………………	2 and 12, respect.
Belt length, width and thickness, cm;	600, 11 and 0.5, respect.
Mech. Archimedean screw height, dia. upper and bottom, cm;	250, 50 and 35, respect.
Mech. Archimedean screw flatted pulley dia., cm	18
Engine- Deutz, German made- power, hp and max. speed, rev/min.	11 hp and 1600 rev/min , respectively

Most of attachments could be changeable to adjust the optimum characteristics of unit performance and facilitate the treatments proceeding under different studied parameters for fractional materials springs, bearings, shoe weights and bolts.

Main parts of the developed unit are shown on the following figures:

Fig. (1) Assembled shoes on disc fixed upon engine flywheel.

Fig. (2) The frictional surface of cylinder assembled on fixed driven shaft.

Fig. (3) The combined unit and Mechanical Archimedean screw.

Fig. (4) A schematic diagram of the mechanical Archimedean screw

A schematic diagram (Fig 5) shows the main parts of the developed unit which is designed by considering the action of centrifugal force base which producing by rotating mass in a circumference direction around a rotated shaft. According to Srivastava *et al.* (1993), the following equations can be used to calculate power, energy and force:

Conducted power is calculated by the following equation:

$$P = Fc * v \quad \ldots\ldots(1),$$

Conducted energy is calculated by the following equation:

$$E = \frac{1}{2} m v^2 \quad \ldots\ldots(2)$$

Conducted force is calculated by the following equation:

$$Fc = m \frac{v^2}{r} \quad \ldots\ldots(3)$$

$$v = \frac{\pi\ d\ N}{60} \quad \ldots\ldots(4)$$

$$\omega = (2\ \pi N)/60 \quad \ldots\ldots(5)$$

$$f = \frac{Fd}{Fc} \quad \ldots\ldots(6)$$

Where:

*P***c =** power inducted on the bottom surface of disk, kW or hp (N.v);

*E***c =** energy inducted on the bottom surface of disk, kJ (N.m);

*F***c =** force inducted on the top surface of shoes, N;

*F***d =** force inducted on the bottom surface of cylinder, N.m***;***

f = fraction factor, less than No. 1 as decimal, dimensionless;

m = shoe mass, kg; N = shaft, rev/min;

ω = angular velocity, rad/sec; *d* = disc diameter; cm

v = disc peripheral speed, m/sec.

The maximum centrifugal acceleration a_{max} $\omega^2 r$ = m/ sec^2

Where, ***g*** = gravity acceleration.

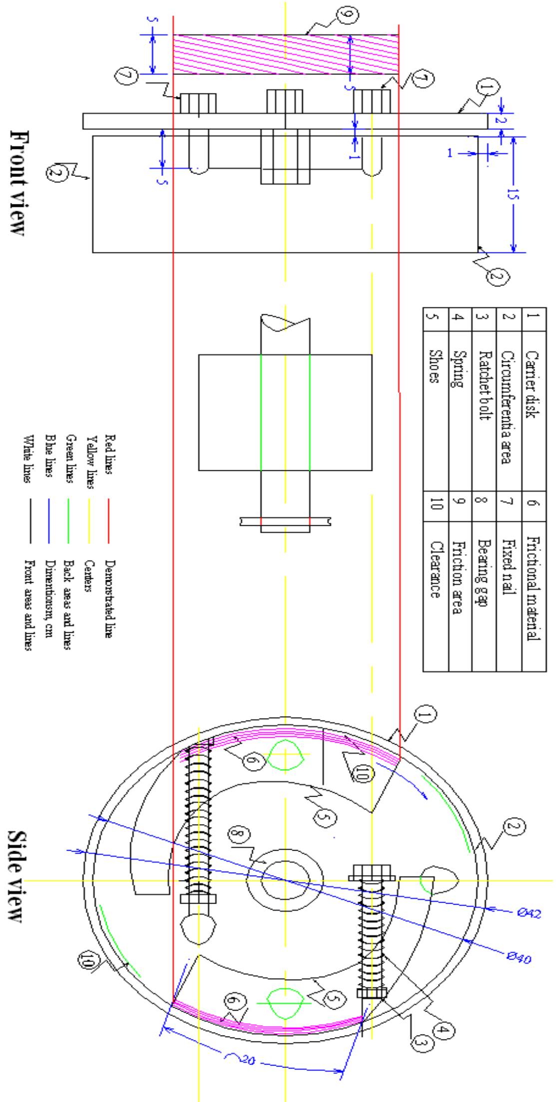


Fig. 5 A schematic diagram of the unit.

According to **Klenin *et al.* (1985)**, the permissible flow rate, ***Q*** of liquid can be evaluated to Tanboor discharge by the following equation:-

$$\boldsymbol{Q} = \frac{\pi}{4} * N * h * \frac{a1 + a2}{2} * \rho * \mu \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where,

Q = the allowable discharge rate, litre/min;

N = shaft speed, rpm; ***h***= water height, m; $\boldsymbol{a_1}$ = lower area of mechanical Archimedean screw, m^2; $\boldsymbol{a_2}$ = upper area of mechanical Archimedean screw, m^2; $\boldsymbol{\rho}$ = density of the threshed material, (1000 kg/ m^3 for water) and

$\boldsymbol{\mu}$ = metal surface loading coefficient (assumed to be 0.02 – 0.04**).**

The experimental procedure:

The primary trail: It was conducted during the winter season of 2013 at a local farm at Faraskur district, Dammietta Governorate, Egypt. The primary trial was to determine the range between suitable point of engine speed to be start before loading action. This action is manually tested and so difficult, slow and has no uniformity in addition to high physical labor. As the internal composition engines are more difficulty operating-starting- in low temperature points which need hot atmosphere. Winter season was chosen to determine the start point (fitted revaluation speed to starting the diesel engine). It was evaluated at 60 rev/min. while clutching action worked at engine speed of 190 rev/min after increasing speed from 60 to 190 rev/min in time of 6 seconds. This speed could be consequently fit in other season as hot point will be higher. A clearance of 5.0 mm between the upper surface of shoe which covered by the frictional material and bottom of cylinder surface which transferring movements to outlet shaft was chosen, that after some trials to select an optimum clearance. A 11 hp Deutz single cylinder diesel engine with 4 reverse was used during all treatments. Previous values change from a season to another and/or engine types.

The second trial: All parts of unit were assembled and adjusted for operating suitable phase after engine starting. Every treatment lasted five minutes after fixing the speed under treatment, all readings were recorded. Water head in well–starting the point of liquid outlet to below - was under of all treatments, 150 cm was selected as controlled conditions. After many hours of operating, coarse contacting area of shoe was more erosion, so it needed to be replaced.

- Test factors

1- Shaft speed: It was measured by laser optical tachometer device with range of 1:99.999 rev/min and accuracy of + (0.05 % + 1 digits). Four levels of speed were examined above -190 rev/min as hitching or coupling point level. They were 350, 600, 850 and 1200 rev/min.

2- Shoes contact area: It was calculated according to the following formula:

Shoes contact area = n*W*L, cm^2.

Where n, number of shoes which equal 2 faces in this study,

W, shoe width, cm and; L, shoe arc length

Three levels of shoes contact areas were estimated. They were 2*5*10= (100); 2*5*15 =(150); and 2*5*20= (200), cm^2.

3- Contacting materials:

Three types of material (rubber belt, linen belt and coarse surface) covered the upper surface of shoe in facing to the original bottom of cylinder. Two of these materials are flexible while the third one is coarse material surface. They were flexible flat rubber piece (rubber belt), flexible and compacted piece of firmly linen fiber (linen belt piece) or coarse of metal layer. Each type of them were individually examined.

Measurements:

1- The percentage of slipping (*S,* %).

$$\textit{Slipping (\%)} = \frac{\text{Engine shaft velocity (rev/min)}}{\text{Outlet unit shaft velocity (rev/min)}} \quad \ldots\ldots\ldots(8)$$

2- Efficiency of mechanical transferring(contacting efficiency), η_{mec} *(%)*.

η_{mec} *(%)* = (100-*S*, %) …………………………………..………..(9)

3- Fuel consumption and power needed, (litre): were estimated by refilling the engine tank with a standard flask for the first and second experiments.

The following formula was used to estimate power consumption by the mechanized system according to ***Hunt (1983),*** as follows:

$$\text{Power (kW)} = \frac{M_f * \rho_f * LCV * \eta_{th} * \eta_{mec} * 427}{3600 * 75 * 1.36} \quad \text{……………..(10)}$$

M_f = fuel consumption, L/h,

ρ_f = density of fuel, Kg / L (For diesel = 0.85);

LCV= calorific value of fuel (10000 kcal / kg);

427= thermo-mechanical equivalent, J / kcal,

η_{th} = thermal efficiency of engine (≈ 35%for diesel engines),

η_{mec} = mechanical efficiency of engine (≈80%).

While, the energy required was estimated using the following equation:

Energy requirements(kW.h/m^3 discharged)=

$$\frac{\text{Power requirement (kW)}}{\text{Actual discharged liquid (m}^3\text{/h)}} \quad \text{……………………………(11)}$$

4- Costs: The hourly cost for machine operation was determined using the following equation, ***Hunt, (1983)***

Hourly cost = P/H (1/A + I/2 + T + R) + (0.9W.S.F) + M/144, .E./h…..(12)

Where:

P = price of machine, L.E,	H =yearly working hours, h/year,
A = life expected of machine, year,	I = interest rate / year,
T = taxes, over heads ratio,	R = repairs and maintenance ration,
0.9 =factor accounting for lubrication	W = power, hp,
S =specific fuel consumption (L/hp.h),	F = fuel price, L.E. / L,
M/144 = monthly wage ratio, L.E,	

The operating cost per m^3 was determined using the following equation:

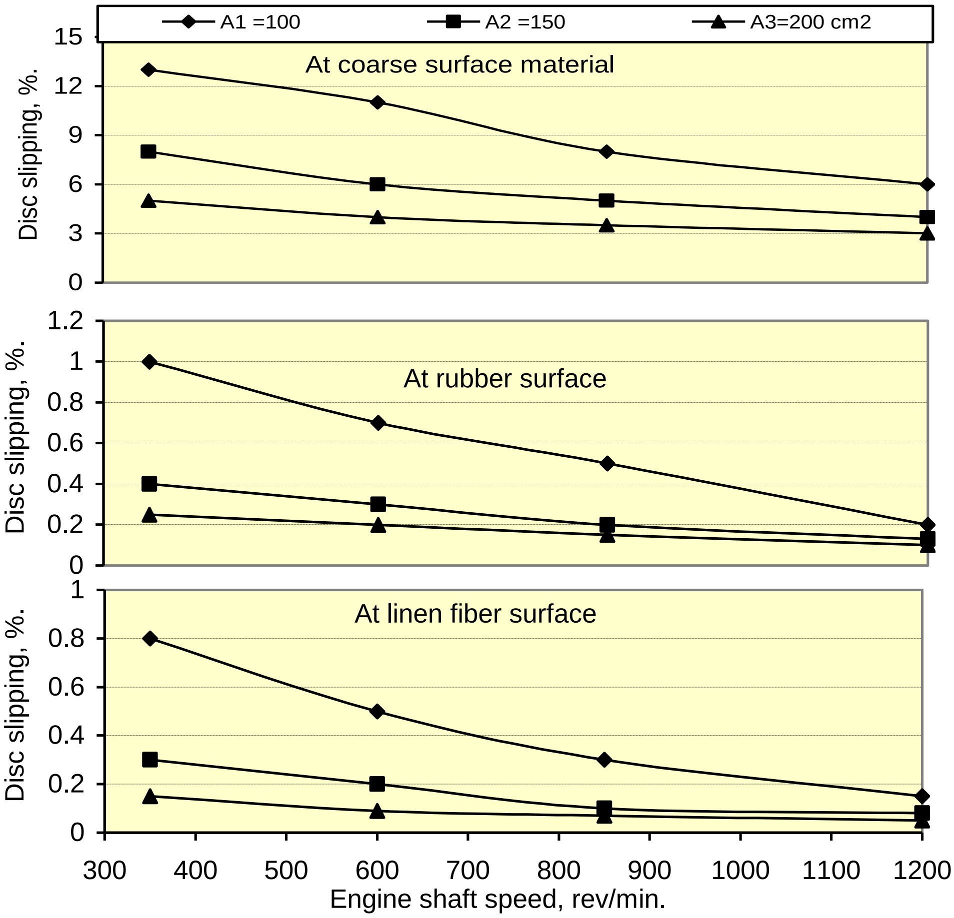
$$\text{Operating costs} = \frac{\text{hourly (LE/m}^3\text{)}}{\text{Actual discharged liquid(m}^3\text{/h)}} \quad \text{…………………(13)}$$

Cost analysis and economic evaluation: The cost analysis **(Oida, 1997)** was performed in two steps. The first step was to calculate the cost of the materials and the fabrication. The second step was to calculate the unit operating cost and were analyzed statistically and the significance according to the probability (P < 0.05) was evaluated by the SPSS program.

RESULTS AND DISCUSSION

1- Effect of engine shaft speed on disc slipping

Figs. 6 show the effect of engine shaft speeds, rev/min on the percentage of disc slipping, (*S, %*) at different, types of contacted materials under their area levels, cm^2. It was obvious that increasing engine shaft speed resulted in decreasing slipping values for all different types of frictional materials and its contacted areas, that is may due to increasing the speed resulted in increasing centrifugal force which caused more clutching action between cylinder bottom and shoes affective contacting surface. Maximum slipping value was 13% at coarse surface material and with minimum speed of 350 rev/min and minimum value was 0.05% at linen fiber surface with maximum speed of 1200 rev/min. Rubber material surface gave medium values between coarse and linen fiber materials in all levels of speed and contacted area.



Figs 6. Effect of engine shaft speeds, rev/min on the percentage of disc slipping, (*S, %*) at different, types of contacted materials under their area levels, cm^2.

2- Effect of contacting area on disc slipping

Fig. 7 showed the effect of contacting area, cm^2 on the percentage of disc slipping, at different, types of contacted materials under different engine shaft speeds. It could be concluded that increasing contacted area, cm^2 resulted in decreasing slipping, (*S, %*) values for all different types of frictional materials at all levels of engine shaft speed. This result was due to increasing frictional area increasing clutching action between cylinder bottom and shoes. Maximum slipping value was at A_1=100 cm^2 at coarse surface material and with minimum speed of 350 rev/min while minimum slipping was at A_3=200 cm^2 at linen fiber surface with maximum speed of 1200 rev/min. Rubber material surface A_2=150 cm^2 gave medium values between coarse and linen fiber surface under all levels of speed and contacted area.

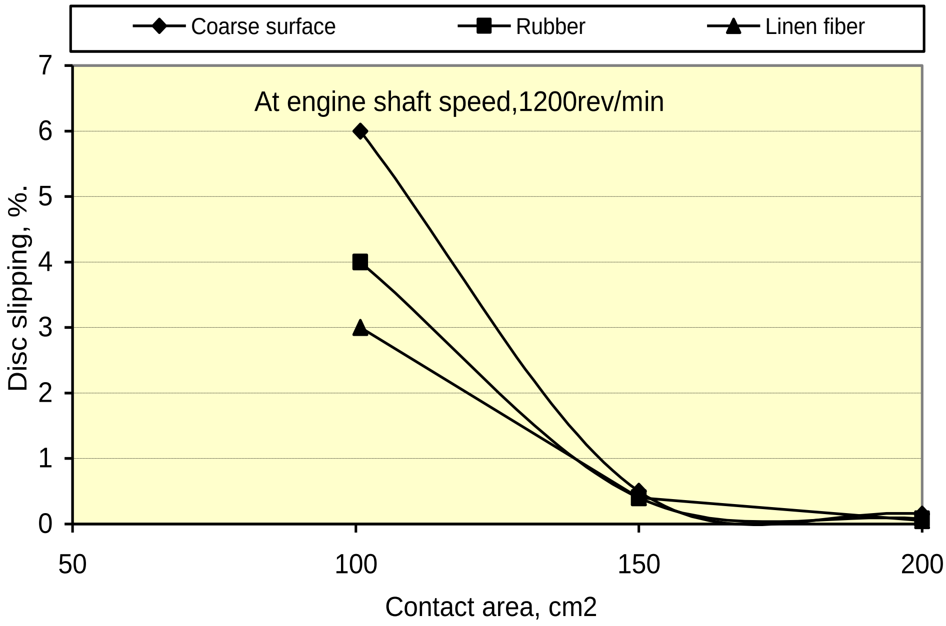
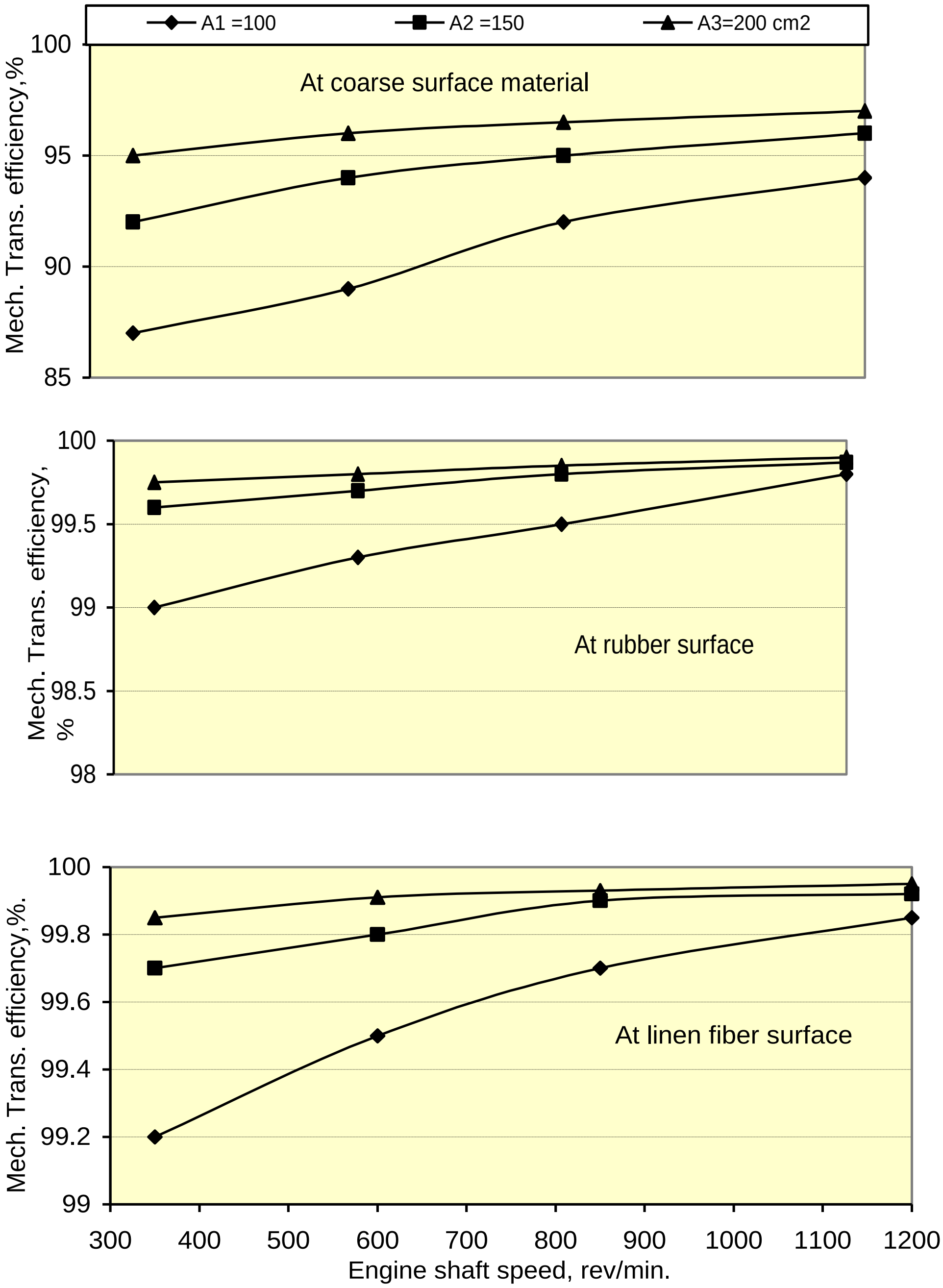


Fig 7. Effect of contacted area, cm^2 on the percentage of disc slipping, (*S, %*) at different, types of contacted materials under engine shaft speed 1200 rev/min.

3- Effect of engine shaft speed on mech. Trans. efficiency, (η_{mec}, %)

Figs. 6 showed the effect of engine shaft speeds, rev/min on the percentage of mechanical transferring efficiency, (η_{mec}, %) at different, types of contacted materials under their area levels, $cm^{2.}$ It was clear that increasing engine shaft speed resulted in increasing mech.trans. efficiency, (η_{mec}, %) values for all different types of frictional materials and contacted areas. That is may be due to increasing the speed, increasing centrifugal force which caused more clutching action between cylinder bottom and shoes affective contacting surface. Maximum efficiency value was 99.95% at linen fiber surface with maximum speed of 1200 rev/min and minimum value was 87% at coarse surface material and with minimum speed of 350 rev/min. Rubber material surface gave medium values between coarse and linen fiber material under all levels of speed and contacted area.



Figs 7. Effect of engine shaft speeds, rev/min on the percentage of mechanical transferring efficiency, (η_{mec}, %) at different, types of contacted materials under their area levels, cm^2.

4- Effect of contacting area on mech. Trans. efficiency, (η_{mec}, %)

Fig. 8 showed the effect of contacted area, cm^2 on the percentage of mechanical transferring efficiency, (η_{mec}, %) at different, types of contacted materials under different engine shaft speed reported that increasing contacted area, cm^2 resulted in increasing mechanical transferring efficiency, (η_{mec}, %) values for all different types of frictional materials at all levels of engine shaft speeds. This is may be due to increasing frictional area increasing clutching action between cylinder bottom and shoes. Maximum efficiency value was at A_3=200 cm^2 at linen fiber surface and with 1200 rev/min shaft speed while minimum value was at A_1=100 cm^2 under coarse surface material and minimum speed of 350 rev/min. Rubber material surface A_2=150 cm^2 gave medium values between coarse and linen fiber surface under all levels of speed and contacted area.

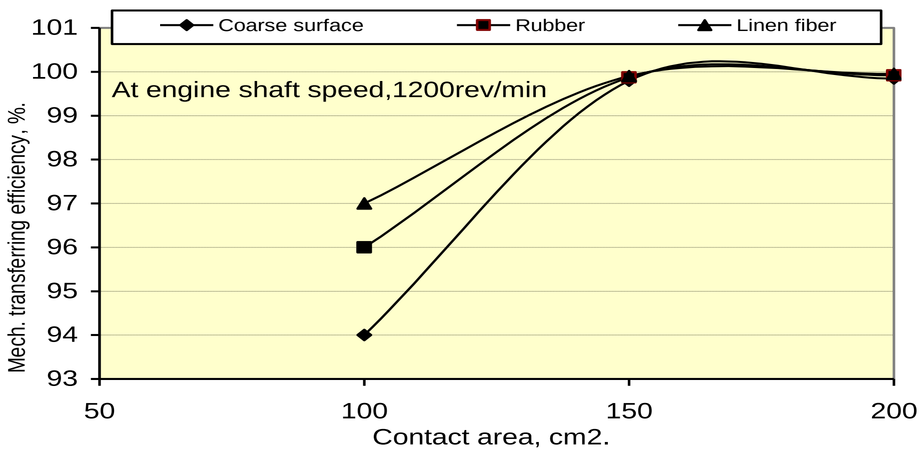


Fig 8. Effect of contacted area, cm^2 on the percentage of mechanical transferring efficiency, (η_{mec}, %) at different, types of contacted materials under engine shaft speed 1200 rev/min.

5- Effect of engine shaft speed on fuel consumed (litre/h) under contacting area of 200 cm^2

Data in fig. 9 showed the effect of engine shaft speeds, rev/min on the fuel consumed (litre/h) with linen fiber surface and contacted area A_3=200cm^2. It was clear that increasing engine shaft speed resulted in increasing fuel consumption because of more power needed to overcome the overload which resulting in increasing water discharge. Maximum fuel consumption was 2.3 litre/min at maximum speed, 1200 rev/min. while minimum value was 1.9 litre/min at minimum speed of 350 rev/min.

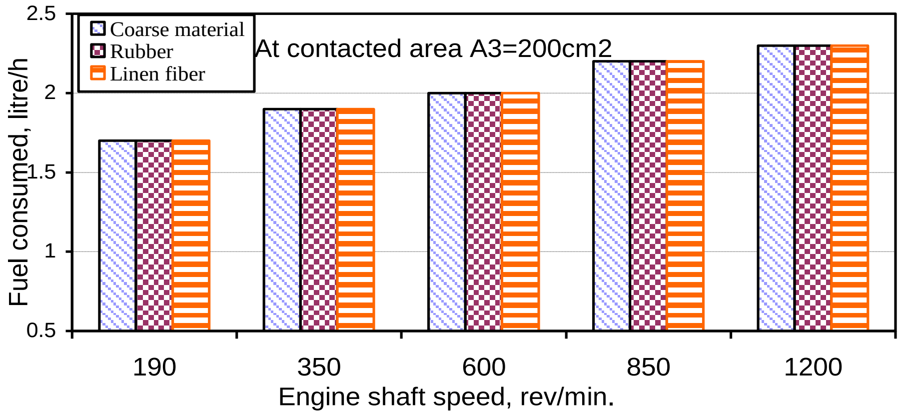


Fig 9. Effect of engine shaft speeds, rev/min on the fuel consumed (litre/h) with linen fiber surface and contacted area A_3=200cm^2.

6- Effect of contacting area of 200 cm^2 on water discharge and power requirements with linen fiber surface

Data in fig. 10 showed the effect of engine shaft speeds, rev/min on the water discharge (m3/min) with linen fiber surface and contacted area A_3=200cm^2. It was indicated that increasing engine shaft speed resulted in increasing fuel consumption and consequently water discharge increased. That is a result of increasing mechanical Archimedean screw discharged fan movement. Maximum fuel consumption of 2.3 litre/h and maximum water discharge was 15 m^3/min. were at maximum speed, 1200 rev/min. while minimum fuel consumption of 1.9 litre/h and water discharge of 10.3 m^3/min at minimum speed, 350 rev/min. under the same conditions. On the other hand power and energy requirements were 6.35 kW and 0.42 kW.m^3/h., respectively under the same conditions of shaft speed, contact area and contacting material while power and energy requirements were 5.24 kW and 0.51 kW.m^3/min under the condition of contact area and contacting material but under shaft speed of 350 rev./min.

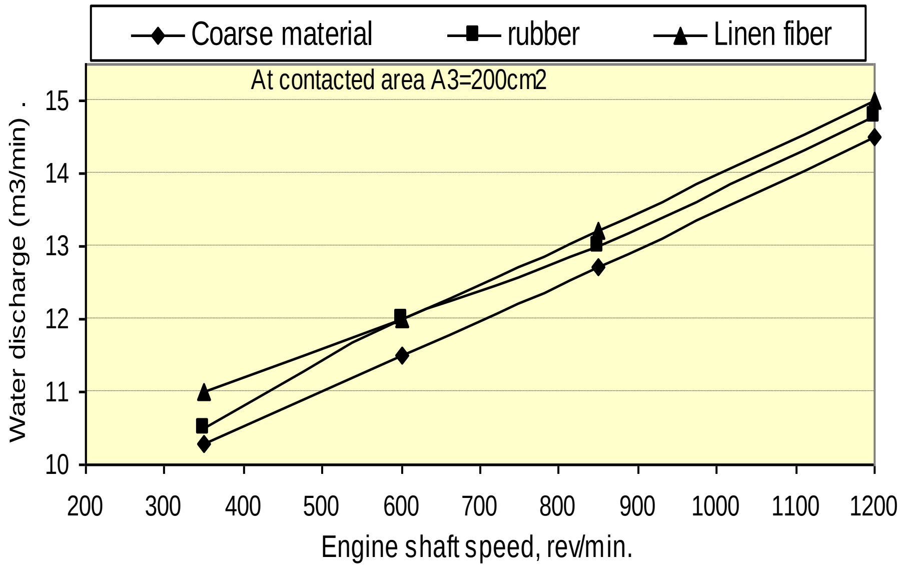


Fig 10. Effect of engine shaft speeds, rev/min on the mechanical Archimedean screw discharge (m^3/min) with linen fiber surface.

Economical studies

The total fabrication cost of the modification in the developed unit including workshop cost was about 500 LE at 2014 price level. The developed unit was achieved at El-Serw Agri. Res Station.

CONCOLUSION

This study was carried out to develop a unit attached to the diesel gasoline engine that turning watering machine. Therefore, it could facilitate starting up the watering machines. The results could be summarized as follow:

- Shaft speed to 1200 rev/min with 200 cm^2 linen contacting material resulted in increasing contacting efficiency to 99.95 %
- Fuel consumption 2.3 l/h and power and energy requirements of 6.35 kW and 0.42 kW.m^3/h, respectively.
- Slip percentage decreased to 0.05% under shaft speed of 1200 rev/min with 200 cm^2 linen contacting material.
- Total costs of fabricating and installing the developed unit were about 500 LE.
- Generally, it is advisable to produce the developed unit in a large scale and install in all watering machines to facilitate and lessen the performance hazards.

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تطوير نظام نقل القدرة في آلات الري

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معهد بحوث الهندسة الزراعية – مركز البحوث الزراعية – الدقي - الجيزة

تتعرض آلات رفع المياه لمشاكل كثيرة مثل تآكل السيور وصعوبة بدء حركة محركات القدرة وكذلك حِمل شَد السير علي كراسي المحاور مما يعرضها للتلف باستمرار ، خصوصاً في نظام الرفع بالسواقي مع صعوبة بِدء نقل الحركة من الآلة إلي مجموعة التروس ، واحتياج ذلك إلي أكثر من عامل لتجهيز نقل القدرة بالسيور مع ما يتبع ذلك من مخاطر جسيمة - أدت فى كثير من الأحيان إلى بتر أيدى أو أرجل الكثيرين ممن يقومون بإدارة وتشغيل هذه الآلات - وكذلك الحال في نقل القدرة للطنابير حيث تكون الآلة في وضع أفقي وطارة الطنبور في وضع رأسي مما يلزم تركيب السير بطريقة معكوسة (مقص) مع صعوبة تركيب السير علي الطارتين فيلجأ إلي تركيب طارتين إحداهما متحركة حول محورها (للإدارة) والأخرى مثبتة علي عمود نقل الحركة وكذلك الحال في طلمبات الري الثابتة حيث تصعب عملية بدء الحركة خصوصاً مع المحركات ذات القدرة الحصانية الكبيرة نسبياً.

أجري البحث في بمحطة البحوث الزراعية بالسرو - مركز فارسكور – محافظة دمياط بهدف تسهيل بدء نقل الحركة في آلات الري الثابتة بتركيب وحدة مطورة علي امتداد عمود إدارة المحرك (الكرنك) بين الحدافة وطارة القائد بهدف تقليل مخاطر نقل القدرة إلي الطارة المقودة وتخفيف حدة تلف وحدات نقل القدرة مثل البلى والسير وبالتالي خفض التكاليف وتأمين العمال من مخاطر التشغيل.

المعاملات التجريبية للدراسة :-

١- سرعة عمود المحرك (٤مستويات ٣٥٠-٦٠٠-٨٥٠-١٢٠٠ لفة\دقيقة)؛

٢- مساحة سطح التلامس (سم٢)؛ (طول وعرض مادة الاحتكاك – ٣ مستويات ١٠٠-١٥٠-٢٠٠ سم^{٢}) و

٣- مادة سطح التلامس (معدن خشن – كاوتش من السير الكاوتش المسطح – نسيج ألياف الكتان المضغوط من سير الشعر).

وقد تم تقدير كل من النسبة المئوية للانزلاق ***S* %**؛ كفاءة النقل الميكانيكي ***η* %** ؛ استهلاك الوقود لتر/ساعة؛ تصرف الطنبور م^{٣}\ دقيقة وكذلك التكاليف بالجنيه مصري.

وأظهرت النتائج أن الزيادة زيادة سرعة عمود التشغيل عند ١٢٠٠ لفة/دقيقة مع سطح احتكاك مصنوع من ألياف الكتان بمساحة تلامس ٢٠٠ سم٢ أدى إلى زيادة فى كفاءة النقل الميكانيكي بنسبة ٩٥.٩٥% مع زيادة معدل استهلاك الوقود ٢.٣ لتر/ساعة وتم حساب القدرة ومتطلبات الطاقة فكانت ٦.٣٥ كيلووات و ٠.٤٢ كيلووات .م^{٣}/ساعة على التوالي ، في حين انخفضت الانزلاق النسبة إلى ٠.٠٥٪. وقد تم تقييم تطوير وتركيب وتشغيل الوحدة المطورة - على حسب الأسعار الحالية - فكان ٥٠٠ جنيه مصرى تقريباً. وعموماً كانت أفضل النتائج عند أعلي سرعة تحت الدراسة وهي ١٢٠٠ لفة\دقيقة ومادة احتكاك المصنعة من نسيج ألياف الكتان المضغوط (السير الشعر) ومساحة تلامس٢٠٠ سم^{٢} لمادة الاحتكاك. وتوصي الدراسة بإنتاج الوحدة المطورة على نطاق واسع وتركيبها في جميع آلات الري الثابتة لتسهيل نقل القدرة وتقليل المخاطر.