Design of a one-row potato digger harvester

A thesis submitted in partial fulfillment of the requirements for the degree of B.Sc. (HONS) in Agricultural & Biological Engineering

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DECLARATION OF ORIGINALITY

I declare this report entitled “Design of a one-row potato digger harvester” is my own work except as cited in references. The report has been not accepted for any degree and it is not being submitted currently in candidature for any degree or other reward.

Signatures: ___________________ ___________________ ___________________

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Names: _______________________

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Date: ________________________
DEDICATION

I dedicate this dissertation work to my family and many friends.

A special feeling of gratitude to my loving parents whose words of encouragement and push for tenacity ring in my ears.

I also dedicate this dissertation to my many friends who have supported me throughout the process. I will always appreciate all they have done.

I dedicate this work to everyone who have taught me a letter.
ACKNOWLEDGEMENTS

I wish to thank my professors who were more than generous with their expertise and precious time. Special thanks to Dr. Amar Hassan El-sheikh my supervisor for his countless hours of reflecting, reading, encouraging and most of all patience throughout the entire process.

I would like to acknowledge and thank my school division for allowing me to conduct my research and providing any assistance requested.

I am grateful too for the support and advice from my colleagues in school of engineering.
Abstract

Potatoes are the agricultural commodities that have the potential to be developed in Sudan. At harvest, the method used was very simple, just use the hoe. The farmers complaining for the need so much work force for harvesting while the labor cost are getting increase, and the time spend for harvesting process are too long. Even if there is a tool for foreign-made potato harvesters are very expensive and not suited to the conditions of potato farming in Sudan.

The machine consist of the two main part, which are potatoes **digger** (scraper) to scrap potatoes from the soil, potatoes elevator and **separator** (screener) used to separate potatoes from the soil. This project focusing on the design of the digger harvester parts.

In this project, we identified and designed the potato digger harvester with specification below:

Digging unit has Length 466.7 mm, width of the digger 900 mm, width of notch 80 mm, thickness 9 mm, angle of inclination 40°, number of notches 9, obtuse angle of the notch 136°.

Separation unit divided to first separator has length 1.4 m, angle of inclination 22°, speed 2.5 m/s.

The second separator has a length 1.2 m, angle of inclination 15°, speed 1.8 m/s.

Mechanical parts of the separator, diameter of the flat belts pulleys 180 mm, diameter of the v-belts pulleys 180 mm for the first separator. And 230 mm for the second separator. Gears has a module= 7 mm, circular pitch= 22 mm, No. of teeth= 26

Tiers has a Width of the tire 180 mm, diameter of tire 800 mm and The entire machine dimensions and speed Length= 3 m, width= 1.1 m, travel speed= 1.1 m/s and the power requirement to cut and lift potato tubers from the soil is 1072 W and the power requirement for sieving and extracting soil by separators is 11000 W.
الملخص

تعتبر البطاطس من السلع الزراعية التي يمكن تنميتها في السودان. حيث نجد أن طرق الحصاد المتبعة في السودان بسيطة جدا حيث يتم استخدام المجرفة.

في الآونة الأخيرة كثرت الشكوى من الزراعة نتيجة للجهد الكبير المبذول لاقتلاع الدرنات بالإضافة إلى أن كلفة العملة الأجنبية في الأزديم وأيضا لا تتم عملية الطويلة المطلوبة لانجاز عملة الحصاد، وحتى لو تم استخدام حاصدة أجنبية مصنوعة خارج السودان نجد أنها باهظة الثمن وغير ملائمة لظروف الزراعة واختلاف المناخ في السودان.

حاصدة البطاطس تنقسم إلى قسمين:

الحفار: يقوم بنزع درنات البطاطس من تحت سطح الأرض حيث يقوم بتفكيك التربة حول البطاطس.

الغربال (الحصيرة): تقوم بفصل درنات البطاطس من التربة. حيث في هذا الكتاب سيتم بالتفصيل التركيز على هذين الجزئين.

في هذا الكتاب سيتم توضيح كيفية إيجاد المتطلبات التصميمية وابعادها كما موضح أدناه:

وجد أن أبعاد الحفار الطول 766.4 مم، العرض القياسي 999 مم، عرض السكينة 80 مم، سمك السكينة 9 مم، زاوية الميلان 40 درجة، عدد السكاكين 9، زاوية افراج السكينة 136 درجة.

تم تقسيم وحدة الحفار (الحصيرة) إلى الحفار الأول والغربال الثاني، وأوجد أن أبعاد الحفار الأول: الطول 4.1 متر، زاوية الميلان 22 درجة، السرعة 0.25 متر/ثانية.

وجد أن أبعاد الحصيرة الأولى: الطول 6.7 متر، زاوية الميلان 22 درجة، السرعة 2.2 متر/ثانية.

وجد أن أبعاد الحصيرة الثانية: الطول 6.2 متر، زاوية الميلان 62 درجة، السرعة 6.0 متر/ثانية.

ووجد أن أبعاد البيكانيكية للحصيرة (الغربال) الأول قطر البكرات 80 مم بالنسبة للسور المسطحة وعلى شكل حرف في أما الحصرية أو الغربال ثاني قطر البكرات 230 مم.

وجدت ابعاد التروس بقياس (موصول) 7 مم، طول خطوة 22 مم، وعدد الأسنان 26.

تم إيجاد ابعاد عجلات الحاصدة حيث وجد أن قطر عجلات 800 مم وعرضها 180 مم.

الإبعاد الكلبي للحاصدة حيث بلغ طولها 3 أميال، عرضها 1.1 أميال السرعة الأمامية 1.1 أميال/ثانية، القدرة المطلوبة لرفع ورفع البطاطس من باطن الأرض 1072 واط والقدرة المطلوبة لفصل وغرابة درنات البطاطس من التربة عن طريق الحصرية 11000 واط.
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CHAPTER ONE

Introduction
1. Introduction

The Sudan is generally a very flat country, most of its parts range between 400 and 450 m AMSL. Only on three of its boundaries are there extensive mountainous stretches: the Red Sea Hills and the foothills of the Ethiopian mountains on the east, the Imatong and Dongotana Mountains and the Nile-Congo watershed on the south and Jebel Marra on the west. In the centre, the Nubba Mountains and the Inga Sana Hills are the only prominent mountainous areas.

The most important physical feature of the country is the River Nile which bisects it from south to north. Most of the main axis of the river is within the Sudan and all its tributaries run most of their lengths and converge within it too. That makes the Sudan more worthy of being called the land of the Nile though it is much less dependent on the river than Egypt, being endowed with adequate rainfall in many of its parts.

Rainfall varies from almost nil in the extreme north to 1500 mm per annum in its south-western boundaries. This is the main factor defining the country's agro-ecological and vegetation zones. These zones extend from the desert in the north to the acacia desert scrub, acacia short grass scrub, acacia tall grass forest, forests and swamps and grassland in the south. During the last few decades, there was a noticeable southwardly retreat of isohyets coupled with more frequent droughts. This may be a constant trend or just a phase of a long cycle. This trend, combined with overgrazing and the removal of the tree cover for various purposes, is causing desert encroachment and perhaps a similar retreat of the boundaries of all the traditionally acknowledged ecological zones. There are also changes in the quality of their vegetation composition. Some species, which were once dominant or very conspicuous, have greatly dwindled, some almost to the brink of extinction.

The population of the Sudan is about 26 million people of whom some 80 percent are rural. They form a great mosaic of ethnic, tribal, linguistic, religious and cultural affiliations and traditions. Sudan has a domesticated animal wealth of over 60 million heads dominated by cattle, sheep, goats and camels. The country has also a great wealth of wild life extending from big game in the south and middle to the jerboa, snakes and antelopes of the desert in the north.

The Sudan is an agricultural country. Eighty percent of its population rely on agriculture for living. Agriculture employs 90% of the country's labour force and its industry - and those whom it employs- is mostly dependent on its agricultural products. Agriculture contributes about 35% of Sudan's GDP, the greatest of all sectors. The country's exports and foreign cash earnings are 90% agricultural

1.1 Agricultural Economy in Sudan

The agriculture sector is the most important economic sector in the country. It contributes on average about 43% of the country Gross Domestic Product (GDP) during the period 1999-2006 (table 1.1). The sector provides employment for about 70 percent of the country’s population, and provides inputs to many major manufacturing industries (e.g., edibles oils, leather, and sugar). Agriculture historically generated the bulk of Sudan’s foreign exchange earnings through a diversified basket of exports,
which can be broadly classified into three categories, that includes field crops exports, animal and forest exports. The major field crops include sorghum, millet, cotton, sesame and groundnut, while animal exports include sheep, camels and cattle, and, gum arabic represents the major forest exports. Although several of these have enjoyed strong growth, agricultural exports are now lower than they were in the late 1960s and early 1970s. Table one show that agricultural exports were the main source of foreign currency before oil exploitation in 1999, agriculture exports share represented on average 20.6% of the total country’s exports during the period 1999-2006, this share has declined to only 10% in 2006. Wheat is the major imported food in Sudan, the value of imported wheat has increased from 83.8 million US$ in 1999 to 286.9 million US$ in 2007 (Bank of Sudan, 2006).

During the last two years the world market prices of food has reached unprecedented levels. In 2007 the international food price index rose by nearly 40%, compared with 9% the year before, and in the first three months of 2008 prices increased further, by about 50% (von Braun et al 2008). Between January 2007 and January 2008 wheat nominal prices rose by 240% and real prices by 172%. Wheat export prices from USA climbed from $375/ton in January to $425/ton in February 2008. This comes on top of a 63% increase in global wheat prices over the past three years and a 33% increase in overall global food prices (World Bank 2008). The FAO Food Price Index (FAO Website 2008) has been steadily rising on monthly basis since 2006 to reach a record of 219 points in June 2008. The Food and Agriculture Organization (FAO) has pointed out that; the dramatic increase in food world market prices is caused by factors related to both supply and demand of food in the world. Regarding the supply side, weather related production short falls, the declining stock levels and the increasing fuel costs arises as main factors that have negatively affected the supply of food in the world. On the demand side, the increasing demand for agricultural commodities for biofuels production and the changing structure of food demand in emerging economies are considered as major factors that has increased world food prices (FAO, 2008)
Table 1.1: Contribution of Agriculture to the GDP and exports share in Total exports in Sudan (1999-2006)

<table>
<thead>
<tr>
<th>Year</th>
<th>Share of Agriculture in GDP (%)</th>
<th>Agriculture Exports (Million USS)</th>
<th>Share of Agriculture Exports in Total Exports (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>49.8</td>
<td>432.0</td>
<td>55.4</td>
</tr>
<tr>
<td>2000</td>
<td>46.4</td>
<td>372.0</td>
<td>21.3</td>
</tr>
<tr>
<td>2001</td>
<td>45.6</td>
<td>240.6</td>
<td>14.9</td>
</tr>
<tr>
<td>2002</td>
<td>46.0</td>
<td>356.2</td>
<td>18.8</td>
</tr>
<tr>
<td>2003</td>
<td>45.6</td>
<td>410.3</td>
<td>16.1</td>
</tr>
<tr>
<td>2004</td>
<td>39.2</td>
<td>590.7</td>
<td>16.5</td>
</tr>
<tr>
<td>2005</td>
<td>38.6</td>
<td>578.8</td>
<td>12.0</td>
</tr>
<tr>
<td>2006</td>
<td>39.2</td>
<td>569.4</td>
<td>10.0</td>
</tr>
<tr>
<td>Average</td>
<td>43.8</td>
<td>443.8</td>
<td>20.6</td>
</tr>
</tbody>
</table>

Source: Bank of Sudan, Annual reports

Figure 1.1: shares of main economic sectors in GDP, Sudan (1965-2004)  
(Source: Web Board (WDI Indicators 2006) and Bank of Sudan Annual Reports)
1.2 Sudan agricultural subsectors

Agriculture in Sudan can be divided into three main subsectors: the traditional rain-fed, the mechanized rain-fed and the irrigated subsectors.

1.2.1 The traditional rain-fed subsector:

This consists of millions of small subsistence farmers. These farmers grow sorghum, pearl millet, finger millet, cassava or maize for food and sesame, groundnut and some minor crops for cash. They usually keep some goats, sheep or cattle. They depend mostly on family labour, use locally made hand tools in farming, grow their favoured landraces and produce their own seeds. They use no fertilizers or pesticides and are thus greatly self-reliant for production inputs. These farmers -with their varied traditions, diverse ecological zones of production and conservatism- are the great maintainers of germplasm diversity.

1.2.2 The mechanized rain-fed subsector:

This comprises about 10,000 big farmers with farms of 1,000-2,000 feddans* and a few big companies with holdings of 20,000 - 200,000 feddans. Land preparation and seeding are mechanized but weed control and harvest are still largely manual. Of the subsector's annual area of 7-12 million feddans, sorghum occupies 80-85%, sesame 14-16% and cotton, sunflower and pearl millet and guar combined 1-2%. This subsector produces about 70% of the country's sorghum, 40% of its sesame and almost all of its sunflower and guar.

The subsector is fully market oriented. To meet the consumers demand it mostly grows landraces of sorghum and sesame, an improved variety of cotton, introduced varieties of guar and hybrids of sunflower.

1.2.3 The irrigated subsector:

This accounts for about 4 million feddans* of the country's crop area. It is dominated by the very large gravity irrigated Gezira, Rahad, New Halfa and Suki schemes. These schemes are managed by the government and cultivated by thousands of tenant farmers who grow almost all the country's cotton, most of its wheat, 35% of its groundnut and 10% of its sorghum. Pump irrigation accounts for about 25% of the irrigated area. Crops of the bigger pump schemes on the White and Blue Niles are almost similar to those of the gravity irrigation. The few big and hundreds of small pump schemes in Khartoum, Nile and Northern states produce most of Sudan's fruits, vegetables, winter legumes and spices. They also produce a good portion of wheat. There is a small area that is flood irrigated in two river deltas in eastern Sudan that grow cotton, sorghum, millet and castor.

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2. * 1 Feddan = 0.42 ha
From above it is apparent that the potato is not one of the major crop produced in Sudan, though it has the potential to be developed.

1.3 Potato crop

The potato (Solanum tuberosum) is a herbaceous annual that grows up to 100 cm tall and produces a tuber – also called potato – so rich in starch that it ranks as the world’s fourth most important food crop, after maize, wheat and rice. The potato belongs to the Solanaceae or “nightshade”– family of flowering plants, and shares the genus Solanum with at least 1000 other species, including tomato and eggplant.

As the potato plant grows, its compound leaves manufacture starch that is transferred to the ends of its underground stems (or stolon). The stems thicken to form a few or as many as 20 tubers close to the soil surface. The number of tubers that actually reach maturity depends on available moisture and soil nutrients. Tubers may vary in shape and size, and normally weigh up to 300 g each. At the end of the growing season, the plant’s leaves and stems die down to the soil level and its new tubers detach from their stolons. The tubers then serve as a nutrient store that allows the plant to survive the cold, and later regrow and reproduce. Each tuber has from two to as many as 10 buds (or “eyes”), arranged in a spiral pattern around its surface. The buds generate shoots which grow into new plants when conditions become favourable once more. A raw potato tuber is rich in micronutrients – the vitamins and minerals that are essential to health. A medium-size potato contains high levels of potassium and nearly half the daily adult requirement of vitamin C. It is also a good source of B vitamins, and minerals such as phosphorus and magnesium.

Table 1.3: components of potato tuber
Figure 1.2: components of potato plant

Figure 1.3: Chemical composition of potato tuber
1.4 History of Potato in Sudan

The potato was apparently introduced by the British to Sudan in the early twentieth century as a home garden vegetable. Cultivation increased around army posts during the First and Second World Wars in an effort to augment British army rations. This expansion was accompanied by agricultural research in both the northern and southern parts of the country, although these efforts were somewhat disjointed and many records have been lost. The first recorded importation of seed was in 1939 from India, and subsequent imports occurred from Kenya. More systematic research dates from the early 196’s, although research and farming activities have been periodically disrupted by civil and military strife in the south. Although not presently a major food crop in Sudan, demand has increased steadily since independence.

1.5 Sudan production

Table 1.3: Potatoes production quantity (tons), Sudan (1961-2013)

<table>
<thead>
<tr>
<th>Date</th>
<th>Prod. in (tons)</th>
<th>Date</th>
<th>Prod. in (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>22,000</td>
<td>1989</td>
<td>90,000</td>
</tr>
<tr>
<td>1964</td>
<td>24,000</td>
<td>1992</td>
<td>150,000</td>
</tr>
<tr>
<td>1967</td>
<td>25,000</td>
<td>1995</td>
<td>200,000</td>
</tr>
<tr>
<td>1970</td>
<td>26,000</td>
<td>1998</td>
<td>164,110</td>
</tr>
<tr>
<td>1973</td>
<td>22,000</td>
<td>2001</td>
<td>200,506</td>
</tr>
<tr>
<td>1977</td>
<td>22,000</td>
<td>2004</td>
<td>336,000</td>
</tr>
<tr>
<td>1980</td>
<td>15,925</td>
<td>2007</td>
<td>263,900</td>
</tr>
<tr>
<td>1983</td>
<td>15,000</td>
<td>2010</td>
<td>315,000</td>
</tr>
<tr>
<td>1986</td>
<td>20,000</td>
<td>2013</td>
<td>342,754</td>
</tr>
</tbody>
</table>

Source: FAOSTAT

Figure 1.4: Potatoes production quantity (tons)
Figure 1.5: World share for Sudan, Sudan has a world share of 0.1%

Figure 1.6: Top 10 countries in the world, Sudan is #75 in the world ranking.
1.6 Geography and Production zones

Areas of concentrated production include:

**Khartoum.** The area around Khartoum, the capital of the Sudan, accounts for over 70 percent of the country's potato production (Geneif, 1986). Located at the confluence of the Blue and White Niles, Khartoum receives less than 300 millimeters (mm) of rain annually, practically all of it from May to October. The average maximum temperature is over 37° C for ten months of the year and over 34° C for the remaining two, December and January. Soils are generally of alluvial origin, ranging in texture from heavy clays to lighter silty and sandy loam. The silty soils are generally preferred for potato cultivation. Most production occurs on small farms of 0.25 to 5 hectares, mainly for subsistence and for sale in the capital (El Baz, 1974; ARC, 1985).

**Jebel Marra.** The area around Jebal Marra, in the western part of the country, is reported to be the second most important potato production area of Sudan, although production figures are not available. Situated between 1,500 and 3,000 meters above sea level (masl), Jebel Marra has a cool, wet climate well suited to potato production. Soils are generally fertile, derived from volcanic materials in the uplands and from fluvial deposits in the valleys. As in Khartoum, holdings are generally small, and surpluses are marketed in the capital (Geneif, 1986; El Baz, 1974; ARC, 1985; Accatino, nd).

**Kassala.** The Gash Delta area in Kassala Province is often mentioned as a zone of high potential for potato production, though figures on actual production in the area are lacking. The general environmental conditions are roughly similar to those around Khartoum: fertile alluvial soils under a hot, dry climate with strongly seasonal rainfall. Any production would require irrigation. Potential markets exist in Khartoum and Port Sudan (El Baz, 1974).

1.7 Production systems and Constraints

1.7.1 Cropping Calendar

At Khartoum and Kassala, potatoes are primarily a winter crop. Planting generally occurs between the beginning of November and the first week of December, and harvesting takes place three to four months later. Late planting may cause substantial losses in yield due to high temperatures in March and April.

Two crops per year are grown around Jebel Marra. The winter crop is grown with irrigation with planting and harvesting taking place according to the schedule described above for Khartoum. A second crop is grown during the rainy season with planting in June or July, depending on the rains, and harvest occurring about three months later (El Baz, 1974).

The southern area can also support two crops per year, both rainfed. The first crop is planted in March and harvested in July. A second crop can be planted in September for harvest in December (Bayeh & Dirk, 1976; Omoro, 1981).

1.7.2 Cultivation Practices

Little detailed information exists on how potatoes are actually grown in the
Sudan. The general shortage of certified planting material leads most farmers to conserve seed by cutting seed potatoes into pieces with one or two eyes. The failure to disinfect the cut pieces is regarded as a major cause of the development of various viral and other diseases (Accatino, nd; ARC, 1985). In addition, locally multiplied planting material degenerates rapidly in yield and disease resistance (Ali, 1976). In the Khartoum region, the periodic infusion of imported seed potatoes alleviates these problems slightly (Ali, 1976; Taha, 1983).

Use of fertilizer appears to be largely confined to urea application in the Khartoum area. Ali (1976) reports applications of 360 kilograms per hectare (kg/ha) of urea and 240 kg/ha superphosphate, although these figures are not necessarily typical of the area. Awatif (1982) reports 60 kg/ha area and does not mention superphosphate. In general, production takes place with a minimum use of purchased inputs, mechanization, or technical assistance.

Yields are generally very low in all the production zones. Average yields of about 17 tons per hectare (t/ha) have been reported for Khartoum (ARC, 1985; El Baz, 1974). El Baz (1974) reports winter crop yields of about 14 t/ha and rainy season yields of 4 t/ha for Jebal Marra. Kamora (1978) reports yields of 50 to 70 t/ha in the southern Sudan, although this refers to agronomic research on a very small scale. Even here yield is inconsistent, with yields of 16 to 25 t/ha being reported for seed potatoes under professional management (Bayeh and Dirks, 1976).

1.7.3 Harvesting
Potatoes are harvested manually when the vines turn yellow. Tubers are cured for 10 days in the field in shallow pits called “Boata” covered by potato vines.

1.7.4 Disease and Pest Constraints
Viral diseases occur throughout the potato production areas of the Sudan, fostered by local seed multiplication practices and the apparent absence of rotation. This is especially true in Jebal Marra where little or no certified seed is used. PVY and leafroll virus have been noted as have such bacterial diseases as soft rot and fungal diseases such as early blight, late blight, and powdery mildew. Major insect pests include termites, cutworms, potato leaf beetle, aphids, white flies (Bamesiatabasi) and tuber moth (El Swafie, 1984; Taha, 1983; Ahmed, 1981).

1.8 Varieties and seed system
The predominant variety around Khartoum is Alpha, generally preferred due to its suitability to silty soils and its long dormancy. Geneif (1986) indicates that Alpha is poorly suited to climatic conditions around Khartoum, and that its predominance constrains potato yields in this region. Desiree and Arka, though high yielding with good storage qualities, are not popular, reportedly due to their pink skin. Spartaan, though not yet widely adopted, appears well suited to clay rich soil (Ali, 1976; Taha, 1983).

Certified seed potatoes, mainly Alpha, are imported from the Netherlands each year. Limited volume and high prices mean that the imported seed is available for only a small proportion of farmers. Moreover, the imported seed typically arrives late in the
planting season due to congestion at Port Sudan and lack of reliable transport, resulting in lower yields. (Geneif, 1986). For these reasons, cultivation in the Khartoum region generally relies on local multiplication of seed material.

Around Jebel Marra, most production consists of local varieties apparently derived from material introduced by the British earlier in this century. Multiplication is done locally by individual farmers (El Baz, 1974; Accatino, nd). Little information is available regarding varieties, means of seed production, or selection criteria.

![Figure 1.7: some tubers varieties](image)

1.9 Consumption, Storage and Marketing

1.9.1 Consumption

Little information is available on consumption. The eastern region consumes about 29 percent of total potato production, mostly in towns such as Port Sudan, Kassala, Gedarif, and New Halfa.

1.9.2 Storage

Three methods of storage have been described (Mohamed, 1985):

- **Cold stores**: In Khartoum province and Omdurman, there were four large private cold stores in 1985 with a combined capacity of less than 5,000 tons (El Shafie, 1984; Mohamed, 1985). While these provide quality storage for up to five months, the limited capacity, expense, and transportation requirements mean that cold storage is available only to a small number of farmers (Geneif, 1986; Accatino, nd; El Shafie, 1984).

- **On-farm-storage**: Most farmers store potatoes on the farm in houses, grass storage huts, and straw covered pits. Losses of 40-60 percent are common, and potatoes stored on farm can suffer complete loss (Accatino, nd). El Shafie (1984) describes the local storage system in Khartoum province: A pit is dug two meters deep and 1.5 to 2 meters wide. After a period in shaded open air, the potatoes are stored in bulk in the pit, which is covered with dry grass or hay and a layer of dry soil on top. The pit is kept shaded, and occasionally opened to examine and remove diseased and rotten potatoes. By this method potatoes can be stored for three to five months, but generally with a loss of about 30
percent. However, that loss is often compensated by higher market prices at the end of the storage period.

- **In-ground storage**: This system is practiced in the JebdMema area. Farmers leaves tubers in the ground after maturity for up to three months.

### 1.9.3 Marketing
The general absence of reliable storage facilities and transport has a substantial effect on distribution and consumption patterns. Potatoes are available in the market on a seasonal basis, mainly February, March, and April. Early in the harvest season prices are high, leading many farmers to harvest the tubers before they reach maturity. During and immediately after, harvest prices plummet as farmers try to unload their crop before spoilage occurs. Those farmers with access to modern storage facilities can subsequently take advantage of premium prices in the post-harvest season (Ahmed, 1981). Potatoes are apparently marketed with little or no grading (Accatino, nd).

From the above analysis, we can see that the harvesting process represents the main problem in the potato production in Sudan. And so this research was oriented to solve this problem by partially mechanized harvested the potato crop.

### 1.10 Project objectives
The main purpose of this research is to design of one-row potato-digger harvester. To achieve this purpose, the following objectives must be determined:

1. Design requirements.
2. The design of main parts.
3. Dimensions of the digger.
4. The digger plate inclination angle.
5. The separator dimensions.
6. The separator inclination angle.
7. The separator speed.
8. Dimensions of the separator parts.
10. Field capacity of the machine.
11. Energy consumption.
12. The power requirement.
CHAPTER TWO

Literature review
2 literature review

2.1 Harvesting and Potato production

Harvesting the potato crop is a critical part of the entire potato production and marketing operation. Crop yield and quality cannot be increased during harvest, but they can be decreased, sometimes drastically. So harvesting operation is highly important practice that we should pay attention to, and the main purpose of it is harvesting potato in timely manner with minimum damage and cost.

2.2 Methods of harvesting potato

Harvesting can be carried out in 2 ways:

2.2.1 Hand harvesting

The simplest method and most frequently used method in Sudan. It is usually used by the small-scale producer and involves the use of digging stick (shovels) to lever the tubers out of the ground.

2.2.2 Mechanical harvesting

Where may be classified as a complete and partial.

2.2.2.1 Partial mechanized

In this method, the foliage is removed with help of harrow. Then lever the tubers by using plough to be picked up by hand.

2.2.2.2 Complete mechanized

In this method, all stages of harvesting are being done with one machine.

2.3 Potato harvesting stages

stage 1

Potato foliage and stalks need to be removed before harvesting to prevent blight infection of the tubers and to facilitate the passage of the harvester. Burning off also removes any weeds which would interfere with the working of the harvester.

The first stage can be divided into:

* desiccate or “burn-off” the foliage (haulms)
* Cut potato green Haulm before harvest (Disarmament of tubers from the ground

Stage 2
Elevating potato tubers from the soil is called **digging**.

Stage 3
The development of mechanisms to separate potatoes from stones and clods has been directed towards mechanical devices located on the harvesters.

Stage 4
Collecting potato from the surface handily by labors.

2.4 Types of potato harvesters:
Potato harvesters can be divided into two types:

2.4.1 Direct (complete) potato harvester
Complete potato harvesters, carrying out a series of tasks in one operation, can be tractor-mounted, self-propelled, or trailed. Those that are trailed are power driven by the tractor to which they are attached. Additional harvester categories include whether the machine is manned or unmanned, and how many rows it can work simultaneously (normally one or two). While simple harvesters resemble side-loading elevator diggers, more complex models include more complex processes including electronic separation mechanisms.

How it work
As harvesters move through rows of potato crops, adjustable steel discs cut any debris or foliage that may block the mouth of the elevator. These discs can be set to cut soil away from the sides of a row’s ridges in order to reduce soil uptake by the elevator.

Harvesters comprise a digging share, fixed in front of the elevator and attached to its frame, which must be set to cut beneath the lowest potatoes. Once the digging share has undercut and loosened the lowest level of potatoes, the soil and crop is moved onto the elevator web. Soil and debris then fall through the chain web, while the potatoes conveyed rearward to the top of the harvester; this is the primary separation process.

Once at the peak of the harvester, the tops of the potatoes are taken off by an elevator with fitted bars, and carried away; the potatoes fall through the web onto another cross-web conveyor, often consisting of rubber-covered bars. They are transferred to two additional web conveyors in order to remove soil before reaching an adjustable separator. This separator, an endless rotating belt, can be lifted or lowered at the end nearest to the potato conveyor. Potatoes roll down the separator toward a potato conveyor, while other flat or rough objects remain on the separator to be transported onto a stone and trash conveyor. Once fully separated, the potatoes are transferred to a loading conveyor of adjustable height, and moved to a trailer traveling alongside the harvester.
2.4.2 Staged harvesting machinery

There are two main machines in staged harvesting:

Spinners

The spinners that are available vary in type depending on the working conditions—specifically, soil type. A spinner that can work effectively in light soil may not be suitable for use in heavy, dense soil. Some spinners include a single depth wheel to determine the depth at which all potatoes can be lifted, and others have no wheels at all. Certain spinners are fitted with a screen to facilitate gathering by lessening the scattering of the potatoes. Some of these implements consist of a main vertical spinner and an auxiliary spinner to separate potatoes from haulm and soil. While trailed wheel-driven spinners are commonly used, tractor-driven models are more popular. [8]

---

Tractor-driven Spinners

These spinners, using power take-off from the tractor to which it is attached,[9] are widely used due to their manoeuvrability and ruggedness in adverse soil types. As the tractor on which the spinner is attached moves forward, a digging share runs beneath the row of potatoes, loosening them and the soil encompassing them. Following the loosening process, rotating forks, or tines, strike the row at right angles. Two off-centre wheels that are joined by a linkage to which the tines are attached enable the tines to push the potatoes, distributing them sideways, enabling them to be picked up by hand.

Figure 2.4: potato spinner

Elevator Diggers

Elevator diggers, available in one or two-row models, are employed in areas where soil is not too dense or heavy. In wet, sticky soils, operators may opt to use a spinner. These implements are advantageous in that they deposit potatoes completely exposed in a narrow row, easing the task of hand pickers. Elevator diggers, all PTO driven and similar in operation, are available in trailed, semi-mounted, or fully mounted models. Semi-mounted diggers are the most popular;[10] they can lift either one or two rows at a time. These diggers, attached to the linkage arms of a tractor’s hydraulic system, consist of a digging share that cuts beneath the crop of potatoes. In contrast to spinners, elevator diggers raise potatoes to the top of the machine by chain webs. These chain webs consist of straight steel bars linked together with gaps to enable soil and debris to be shaken with adjustable

agitation and fall back onto the field. Operators must ensure that agitation is minimal to avoid tuber bruising. Potatoes, traveling over the rear of the digger, are then placed in a narrow row on the field.

Figure 2.5: two-row elevator digger
CHAPTER THREE

Theory of design of potato digger harvester
3. Theory of design of potato digger harvester

Many researches and studies have been made in potato harvesting, and in this research, we will present some of these studies and their theories. First, let us discuss the stages of potato harvesting.

3.1 Functional process of potato-digger Harvester

Potato-digger Harvester to achieve its function must be performed the following processes:

1. Elevating potato tubers from the soil.
2. Separating potatoes from stones, clods and trashes: depend on state of the soil such as mechanical composition – humidity – stiffness – plasticity – cohesion especially when water added.
3. Elevating potato tubers to the rear and drop it into the hopper to be picked up later.

3.2 Machine parts

Potato digger harvester can be grouped into two main parts

1. Digger
2. Separator and elevator

In the following, illustration of theories for designing these parts:

3.3 The digger

It’s a blade used to cut into the ground, free up the potatoes from the soil and elevate it to the separator.

3.3.1 Design requirements for the digger:

1. Doing an absolute cutting to the soil layer that contains potato tubers (2% loss is allowed) and feed as less as possible of clods and foliage.
2. Not damaging potato tubers.
3. Rarefying the cut layer so hardly

There are two different types of digging blades:

1. Passive: remain stationary as the machine is moving
2. Active: move with respect to the machine

In this design, we will use a passive blade digger.

3.3.2: The passive blade digger:

It is a flat plate fixed inclined from the horizontal.
The digger’s angle of inclination ($\alpha$) has to be as less as possible, to avoid clods sliding and reduce draw resistance.
On the other hand, the value of this angle associated with the height of rear of the digger \((H)\), and working length \((L_d)\) as shown in figure 3.1:

\[ \sin \alpha = \frac{H}{L_d} \]

\[ \sin \alpha = \frac{(H+\Delta)}{L_d} \]  \hspace{1cm} (3.1)

Where \(\alpha\) is the angle of inclination from the horizontal \((\degr)\), \(H\) is the height of the rear of the digger \((\text{mm})\), \(\Delta\) is the clearance \((\text{mm})\), \(L_d\) is the working length \((\text{mm})\).

- According to experiments, with increasing of \(\alpha\) the cleaning operation improve as well.
- In most designs of potato harvesters the value of \(\alpha\) has found to be \((25 - 40 \degr)\) at depth \(H\) of \((180\text{mm} - 250\text{mm})\).
- The smooth sliding of potato and clods on the digger blade depends on \(\alpha\) and has to satisfy the sliding condition:

\[ \alpha \leq 90 - \phi \]  \hspace{1cm} (3.2)

Where \(\phi\) is angle of friction between the soil and blade material.

- Since the cleaning operation of the digger blade depends on the density and shape of the crop foliage, the blade is designed with an obtuse angle \((\gamma_0)\) (as shown in figure...
3.1), and it’s value has to be taken where the foliage is sliding on sides, fasten the digging operation and reduces the losses and overload of the crop and clods in front of the digger blade.

♦ Theoretically the value of \( \gamma_0 \) must satisfy the following:

\[
\gamma_0 = \pi - 2\theta \tag{3.3}
\]

Where \( \theta \) in this case the friction angle between crop foliage and blade material \( \gamma_0 \) usually taken (80° - 100°).

For more clarification:
If we assumed that the force on the blade from the foliage \( P \) and analyzed it into tangential force \( P_1 \) and vertical force \( P_2 \).

Refer to figure 3.1 above

\[
P_1 = \frac{P \cos \gamma_0}{2H}
\]

\[
P_2 = \frac{P \sin \gamma_0}{2H}
\]

From \( P_2 \) comes the force \( F \) affecting on the opposite direction of \( P_1 \).
The movement of foliage on the digger’s blade occurs only under this condition:

\[
P_1 > F
\]

By decreasing \( \gamma_0 \) it has to lengthen the working blade \( L_d \) and that negatively affecting the flow of the clods (cut layer) on the blade. Thus, it has to be taken the least value possible of \( L_d \), and it usually taken (400 – 475mm).

To calculate the number of notches using the following expression:

\[
B_d = ns + nb \tag{3.4}
\]

Where \( B_d \) is the width of the digger’s blade (working width) (mm), \( n \) is the number of notches, \( s \) is the clearance (spacing) between notches (mm), \( b \) is the width of the notch (mm).

♦ \( B_d \) is determined from potato requirement, depth of digging and repose angle of potato in the soil.

3.3.3 Mechanical design of the digger blade
It include the axial load which cause bending and deflection in digger blade, also it comprise shear load which cause fracture. Therefore, the parameters that we must determine is:

1. Thickness of the digger blade \( t \).
2. Sort of material.
3. Screws that joint the blade with the main frame

Ordinarily, selection of material depends **Friction force.** Coefficient of friction between material and soil where it should be very little value to maintain of time life of machine and decreasing the damage of potato tubers. So in the next chapter we will determine all forces affecting in the digger blade.

### 3.3.4 Screwed joints

A screwed joint is mainly composed of two elements (a bolt & nut). The screwed joints are widely used where the machine parts are required to be readily connected without damage to the machine or fastening. This may be for the purpose of holding or adjustment in assembly or service inspection, repair or replacement, or it may be for manufacturing or assembly reasons.

In the specification standards for bolts, the strength is specified by stating ASTM minimum quantities, the minimum proof strength, or minimum proof load, and the minimum tensile strength.

**Stresses due to external forces**

The following stresses are induced in a bolt when it is subjected to an external load.

1. **Tensile stresses**
   
   The bolts usually carry a load in the direction of the bolt axis, which induces a tensile stress in the bolt. The tensile stress of the bolt can be obtained from the load on it by the following expression

   \[
   P = \frac{\pi}{4} d_c^2 \times \sigma_t
   \]

   Where \( d_c \) is root or core diameter of the thread, \( \sigma_t \) is the permissible tensile stress for the bolt material

2. **Shear stress**

   Sometimes, the bolts are used to prevent the relative movement of two or more parts, and the following expression is used to obtain the shear stress of the bolt

   \[
   P_s = \frac{\pi}{4} d^2 \times \tau
   \]

   Where \( d \) is the major diameter of the bolt, \( \tau \) is the number of the bolts.
3.4 Elevator and separator

Its function is receiving crops and clod from the blade and raise it to the top of the machine. Meanwhile, shakes off the clods and dirt.

3.4.1 Separator design requirement is:

1. Achieving highly efficient separation with minimum crop loss and damage.

2. Quality of the separator depends on feed rate of material received from the digger and its properties.

The feed rate can be determined by using the following expression:

\[ q = \rho \times B \times Z \times V \]  

Where \( q \) is the feed rate (kg/s), \( \rho \) is the density of the soil (kg/m\(^3\)) usually taken (1000-1600), \( B \) width of the soil layer (usually equal to the working width) (m), \( Z \) thickness of the soil layer (less than the depth of cut)(m), \( V \) machine forward speed (m/s).

- With increasing of soil moisture content, the density increases.
- The thickness of soil layer depends on the depth of cut.

The relationship between \( Z \) and \( H \) can be expressed with the following empirical equation:

\[ Z = 0.57H - 0.01 \]  

- The above equation used only when \( H \) is in the range of (0.025- 0.05 m).
- The feed rate of potato tubers can be determined in term of crop yield per hectare by using the following expression:

\[ q_p = Y_p \times B \times V \]  

Where \( q_p \) is tubers feed rate (kg/s), \( Y_p \) is crop yield (kg/m\(^2\)).

There are two types used to separate the crop from the other materials:

1. Rod type separator
2. Net type separator

In this design, we will use the rod separator

3.4.2: The rod type separator:
31

Consist of straight steel bars linked together with gaps to enable soil and debris to be shaken with adjustable agitation. Operator must ensure that agitation is minimal to avoid tuber bruising.

- The agitation process is done by placing an elliptical pulley rounding freely in the middle between the circular pulleys. As a result of the rounding of the pulleys the rods moves linearly with constant speed (v).
- The separator takes his movement from PTO of the tractor and transported by the gearbox, which reduces the PTO velocity and the motion transmission between them is done by using a circular pulleys and V-belts.
- Movement of the sieve itself is done by gears and circular pulleys using flat belts.

**3.4.3 Separator dimensions:**
Separator is consist of steel bars parallel to each other with some gaps fixed on chain or belt (long working life)

- Quality of separator depends on the following parameters:

Width of separator, length of separator, angle of inclination, speed of separator and degree of vibration.

Fig. (3.2): geometrical dimensions of separator

- **Width of separator** depends on crop rows and width of harrow.

- **Length of separator** depends on separation performance and tubers losses.

- Increasing the length increases the performance. Nevertheless, also increases losses and machine dimension (affecting the machine balance). The length usually taken (1.4- 1.8) m.
The length of the separator can be determined by the following expression

\[
L = \frac{v_s^2}{g(f \cos \alpha_s - \sin \alpha_s)}
\]  
(3.10)

Where \( \alpha_s \) is angle of inclination of the separator, \( v_s \) is the speed of the separator.

Cross-sectional area of the tuber determine the gap between rods \( S_r \), rod diameter \( d_r \), as following:

\[
S_r - d_r \leq d_p
\]  
(3.11)

Mean diameter of potato \( d_p \)

\[
d_p = \frac{3}{4} \sqrt{LWT}
\]  
(3.12)

Where \( L \) is the tuber length (mm), \( W \) is the tuber width (mm), \( T \) is the tuber thickness (mm).

In most designs taken:

- \( S_r \) in the range of (38-42) mm.
- \( d_r \) in the range of (10-12) mm.

-Percent of sieving area from total area of separator usually (%70-%75) the rest is covered by rods.

3.4.4 Angle of inclination (\( \alpha_s \))

Depends on separation and elevation requirement. Small values negatively affect machine dimension and reduces the separation performance, and vice versa. However, great values could cause accumulation of soil and tubers on separator surface.

- The top part of separator usually fixed at angle (20° - 22°).
- In case of using, a second separator usually fixed at angle (12° - 15°).
- Angle of inclination of first separator \( \alpha_s \) depended on coefficient of friction between material of separator and soil \( \theta_i \), it must:

\[
\tan \alpha_s < \tan \theta_i
\]

3.4.5 Speed of separator (\( v_s \)):

The efficiency of separator depends greatly on its speed. Increasing the speed increases the separation and helps to flatten the soil layer over separator area. Nevertheless, shorten the residence time of the soil on separator area and that reduces soil dropping through gaps.
- The speed of first separator (in case of two stages) taken as (1.4 - 1.8) \( V \), Where \( V \) is the forward speed of the machine.

Usually:

- \( v_{s1} \) Taken in the range of (1.5 - 2.5) \( \text{m/s} \).
- \( v_{s2} \) Taken in the range (1.2 - 1.8) \( \text{m/s} \).

Moreover, this must satisfy the following:

\[
v_s \geq V \cos \alpha_s
\]

### 3.4.6 Degree of vibration:

Usually, elliptical pulleys is used to occur the vibration. The ratio between major and minor radius (k) must be

\[
k \geq \sqrt{\frac{3}{7}} , \quad k \geq 0.65
\]

If \( k \) is less than 0.65, the height of throw will increase and cause potato damage.

### 3.4.7 Separator elements

(Elliptical-circular) pulleys, belts (v-belt and flat) and shafts.

Elliptical pulley has major radius \( a \) and minor radius \( b \)

For the elliptical pulley the angular velocity not constant and changing from \( \omega_{max} \) to \( \omega_{min} \)

where:

\[
\omega_{max} b = \omega_{min} a = V \tag{3.13}
\]

Where \( V \) is the linear speed of the rods (\( \text{m/s} \)).

To determine the number of revolutions of the elliptical pulley:

\[
\omega_{mean} = \frac{(\omega_{max} + \omega_{min})}{2} \tag{3.14}
\]

Substitute (3.13) in (3.14):

\[
\omega_{mean} = \frac{V}{\frac{b + a}{2}} \tag{3.15}
\]

\[
\omega_{mean} = \frac{V}{2a} (1 + \frac{a}{b}) \tag{3.16}
\]

Let \( m = \frac{a}{b} \), then

\[
\omega_{mean} = \frac{V}{2a} (1 + m) \tag{3.17}
\]

Since
\[
\omega = \frac{2\pi n}{60}
\]

or

\[
n = \frac{30\omega}{\pi}
\]

then

\[
n = \left(\frac{15V}{\pi a}\right)(1 + m)
\]

(3.18)

or

\[
n = \frac{60V}{l}
\]

(3.19)

Where \( l \) is the circumference of the elliptical pulley

\[
l = \pi \left(1.5(a + b) - \sqrt{ab}\right)
\]

As shown as fig. (3.3) we have an elliptical pulley which affected by Normal force \( N \), friction force \( F \) and centrifugal force \( m\omega_m^2R \)

![Fig. (3.3): Forces affecting by a pulley](image)

To achieve the equilibrium condition for vertical component forces and horizontal component forces at point M.

Equilibrium condition for vertical component forces:

\[
(m\omega_m^2R + N) \sin(\beta - \alpha_s) + F \cos(\beta - \alpha_s) - mg = 0
\]

(3.20)

\[-(m\omega_m^2R + N) \cos(\beta - \alpha_s) + F \sin(\beta - \alpha_s) = 0
\]

(3.21)
But in case of initial movement of the pulley (separator), the normal force \( N=0 \), the friction force \( F=0 \).

Substitute in equations (3.20) and (3.21) we find that

\[
\omega_m^2 R \sin(\beta - \alpha_s) = g \quad (3.22)
\]

\[
\omega_m^2 R \cos(\beta - \alpha_s) = 0 \quad (3.23)
\]

Equation (3.22) determine the relationship between kinematic factor and extraction stage.

Rearrange (3.22):

\[
\frac{1}{\sin(\beta - \alpha_s)} = \frac{\omega_m^2 R}{g} = k \quad (3.24)
\]

Equation (3.23) determine the biggest extraction process, which volatilize to the highest point of \( M \).

Thus,

\[
\cos(\beta - \alpha_s) = 0
\]

\[
\beta = 90 + \alpha_s
\]

Substitution in equation (3.24) we find that

\[
k_1 = 1
\]

We must take \( k > 1 \) to get the proper extraction so we must take

\[
\beta < (90 + \alpha_s)
\]

\[
\sin \beta = \frac{a}{b}
\]

Substitute in equation (3.24) to get proper extraction for kinematic factor

\[
k = \frac{1}{\sin(\beta_2 - \alpha)}
\]

Hence, we can determine the angular velocity \( \omega \)

\[
\omega = \sqrt{\frac{k g R}{(m+1) g}} = \sqrt{\frac{k(m+1)}{2b} g} \quad (3.25)
\]

The linear speed of the pulleys (separator) can be determine by:
\[ v = \omega R = \frac{k \, 2b}{(m+1)} g \] (3.27)

Mean radius \( R \) of elliptical pulley

\[ R = \frac{2a}{m + 1} \]

Condition of high degree of separation of the soil can be occurs if normal component of the acceleration of separator is greater than the normal acceleration of earth gravity (\( g \)).

\[ \frac{v_s}{a} (1 - k^2) = g \]

The frequency is usually taken as (120 rpm).

**3.4.8 Mechanical design of the separator’s parts**

**3.4.8.1 Design of Pulleys & Belts:**

The belts are used to transmit power from one shaft to another by means of pulleys that rotate at the same speed or at different speeds.

In this chapter, we will illustrate the flat (pulleys-belts) and Elliptical pulley which is subjected in the design of potato harvester.

Now we will show the parameters affected on circular(V-belt) pulleys design:

**Material used for belts**

the material used for belts must be strong, flexible and durable. It must have a high coefficient of friction. The belts according to the material used are classified to

Leather belts – cotton or fabric belts - Rubber belts - Balata belts

Usually, leather are used in flat belts and rubber with V-belts.

**Density of belt material**

the density of various materials are given in the following table.

<table>
<thead>
<tr>
<th>Material of belt</th>
<th>Mass density Kg/m3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leather</td>
<td>1000</td>
</tr>
<tr>
<td>Rubber</td>
<td>1140</td>
</tr>
</tbody>
</table>

Table 3.1: Density of some belt materials
Coefficient of friction between belt and pulley

The coefficient of friction between the belt and pulley depends upon the following factors:

- The material of belt.
- The material of pulley.
- The slip of belt.
- The speed of belt.

Velocity ratio of belt drive

It is the ratio between the velocities of the driver and the driven. As shown in Fig. (3.4), the A pulls the belt from one side and delivers it to the other side. Thus the tension in the lower side belt will be more than that in the upper side belt. The tension (lower side) is known as tight side whereas the less tension (upper side) is known as slack side.

![Fig.(3.4) : basic belt drive geometry](image)

Length of an open belt drive

In the open belt drive, both the pulleys rotate in the same direction. The length of belt between two pulleys have diameters $d_1,d_2$ can be determined by the following expression:
\[ l_b = \sqrt{4e^2 - (D_1 - D_2)^2} + \frac{1}{2}(D_1 \theta d_1 + D_1 \theta d_2) \]  \hspace{1cm} (3.28)

Angle of contact between the belt and the pulleys

\[ \theta = 180^\circ - 57 \times \frac{D_1 - D_2}{l} \]  \hspace{1cm} (3.29)

Where:

- \( C \) = Distance between the centers of two pulleys.
- \( \theta \) = angle of contact. (radian)

The nominal range of center distances should be:

\[ D_1 < C < 3(D_1 + D_2) \]

**Ratio of driving tensions for flat belt drive**

Consider a driven pulley rotating in the clockwise direction as shown in Fig.(3.4)

The following expression gives the relation between the tight side and slack side tensions

\[ \frac{T_1}{T_2} = e^{\mu \theta} \]  \hspace{1cm} (3.31)

Where

- \( T_1 \) = Tension in the tight side of the belt,
- \( T_2 \) = Tension in the slack side of the belt, and
- \( \mu \) = coefficient of friction between the belt and pulley.

**2.4.8.2 Gears**

The gear is a mechanical part used to transmit power from one shaft to another by either reducing or increasing the power. However, in this design the gears are used to provide the motion of the separator. To design a gear it has to determine the forces acting on it, which are tangential force and radial force, and determine some geometrical variables which:

**Pitch circle** is a theoretical circle on which calculations are based. Its diameter is called the pitch diameter.

\[ d = mN \]  \hspace{1cm} (3.32)

Where \( d \) is the pitch diameter (mm); \( m \) is the module (mm); and \( N \) is the number of teeth

**Circular pitch** is the distance from a point on one tooth to the corresponding point on the adjacent tooth measured along the pitch circle
\[ p = \pi m = \frac{\pi d}{N} \] (3.33)

Where \( p \) is the circular pitch (mm)

**Module** is the ratio of the pitch diameter to the number of teeth

\[ m = \frac{d}{N} \] (3.34)

**Addendum** is the radial distance from the pitch circle to the outside of the tooth. And it equal to \( m \) for \( \emptyset = 20^\circ \) (pressure angle).

**Dedendum** is the radial distance from the pitch circle to the bottom land. And it to \( 1.25m \) for \( \emptyset = 20^\circ \)

![Spur gear schematic showing principle terminology](image)

**Fig.(3.5): Spur gear schematic showing principle terminology**

There are two forces acting on gear which are tangential force and radial force

- Tangential force can be determined by the following expression

\[ P_t = \frac{2T}{d} \] (3.35)

Where \( P_t \) is the tangential load, \( T \) is the torque (N.m), \( d \) is the gear diameter

- Radial force can be determined by the following expression

\[ P_r = \frac{P_t}{\cos \emptyset} \] (3.36)

**3.4.8.3 Shaft**

The shaft is the component of a mechanical device that transmits rotational motion and
power. It is integral to any mechanical system in which power is transmitted from PTO passing through gearbox. In order to transfer the power from one shaft to another, the various members such as pulleys, gears, etc., mounted on it.

2.4.8.4 Key and key seat

A key is a machinery component placed at the interface between a shaft and the hub of a keys power-transmitting element for the purpose of transmitting torque as shown in fig.(3.5). The key is demountable to facilitate assembly and disassembly of the shaft system. It is installed in an axial groove machined into the shaft, called a keyseat.

![Image of key and key seat dimensions and forces](image)

**Fig. (3.6): dimensions and forces on a key**

In this design a parallel square keys will be used see fig. (3.6) that is suitable for small shafts.

The key seats in the shaft and the hub are designed so that exactly one-half of the height of the key is bearing on the side of the shaft keyseat and the other half on the side of the hub keyseat. Figure (3.7) shows the resulting geometry. The distance T is the radial distance from the theoretical top of the shaft, before the keyseat is machined, to the top edge of the finished keyseat to produce a keyseat depth of exactly H/2. To assist in machining and inspecting the shaft or the hub, the dimensionss and T can be computed and shown on the part drawings. The equations are given in Figure (3.6).
Fig.(3.7): Dimensions for parallel key seats

Key seat consist of three dimensions, As shown in figure(3.7) we found

(a) Chordal height (Y)

\[ Y = \frac{D - \sqrt{D^2 - W^2}}{2} \]  \hspace{1cm} (3.37)

(b) Depth of shaft key seat (S)

\[ S = D - Y - \frac{H}{2} \]  \hspace{1cm} (3.38)

(c) Depth of hub key seat (T)

\[ T = D - Y - \frac{H}{2} + c \]  \hspace{1cm} (3.39)

Where

\[ c = \text{allowance} + 0.127\text{mm clearance for parallel keys} \]

3.4.8.5 Rolling contact bearing

The purpose of a bearing is to support a load while permitting relative motion between two elements of a machine. The term rolling contact bearings refers to the wide
variety of bearings that use spherical balls or some other type of roller between the stationary and the moving elements.

Since the shaft subjected to radial loads. Such loads are typical of those created by power transmission elements on shafts such as spur gears, V-belt drives, and chain drives. So selected radial load bearing.

\[
C = P_d \left( \frac{L_{life}}{10^6} \right)^{1/K}
\]  

(3.40)

Where computed design load \( P_d \), a given design life \( L_{life} \)

\[
L_{life} = (h)(N)(60 \text{ min/hr})
\]  

(3.41)

Where hours of machine operation \( h \), speed of rotation shaft \( N \) (rpm)

**Fig.(3.8):** Single-row, deepgroove ball bearing

**Table (3.2):** illustrate recommended design life for bearings for different machines
<table>
<thead>
<tr>
<th>Application</th>
<th>Design life</th>
<th>$L_{10}$ h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic appliances</td>
<td>1000-2000</td>
<td></td>
</tr>
<tr>
<td>Air craft engines</td>
<td>1000-4000</td>
<td></td>
</tr>
<tr>
<td>Automotive</td>
<td>1500-5000</td>
<td></td>
</tr>
<tr>
<td>Agricultural equipment</td>
<td>3000-6000</td>
<td></td>
</tr>
<tr>
<td>Elevators, industrial ,fans ,multipurpose gearing</td>
<td>8000-15000</td>
<td></td>
</tr>
<tr>
<td>Electric motors industrial blowers general industrial machine</td>
<td>20000-30000</td>
<td></td>
</tr>
<tr>
<td>pumps and compressors</td>
<td>40000-60000</td>
<td></td>
</tr>
<tr>
<td>critical equipment in continuous 24-h operation</td>
<td>10000-200000</td>
<td></td>
</tr>
</tbody>
</table>


### 3.5 Gearbox

**Gearbox** is a transmission that uses gears and gear trains to provide speed and torque conversions from a rotating power source to another device. In this design we want to change the direction of the drive in the gear system by 90 degree, thus we will use a set consist of a spur gear (pinion) and bevel gear.

- To design a gearbox the following procedures must followed

**Design of bevel gear:**

\[
i = \frac{N_{in}}{N_{out}}
\]

\[
\gamma_P = \tan^{-1} \left( \frac{1}{i} \right)
\] (3.42)

\[
D_P = m \times Z_{(P)}
\]

\[
D_m = D_P - b \tan(\gamma_P)
\] (3.43)

\[
\frac{L}{4} \leq b \leq \frac{L}{3}
\]

\[
L = \frac{D_P}{2 \sin(\gamma_P)}
\] (3.44)

Where:

$\gamma_P$ = Cone angle, $i$ = Ratio between input speed and output speed (Reduction)

$Z_{eqP}$ = Equivalent number of teeth (pinion), $Z_P$ = Number of Teeth (pinion)

$D_m$ = Main diameter

**Check (1):**
Static check (Lewis check) :

\[ 1.25 \leq \frac{F_s}{F_t} \leq 1.85 \]

\[ F_t = \frac{T}{R} = \frac{P}{\omega \cdot R} = \frac{P}{V} \quad (3.45) \]

\[ \omega = \frac{2\pi N}{60} \]

\[ V = \frac{\omega \cdot D_p}{2} \]

\[ F_s = \frac{\sigma_y}{S.F} \cdot m \cdot b \cdot y \quad (3.46) \]

Where:

- T = Torque (N.mm)
- \( P = \) power (W)
- R = Radius of pinion (mm)
- \( \sigma_y = \) Tensile yield strength of the material (MPa)
- S.F = Factor of safety
- m = module
- b = face width gear (mm)
- Face width for spur gear (b) = \( 3\pi \cdot m \) .... \( 4\pi \cdot m \)
- y = Load at Tip
- (dependent of the pressure angle (\( \varphi \)) and number of teeth)

Check (2)

Dynamic check:

\[ 1.25 \leq \frac{F_w}{F_d} \leq 1.85 \]

\[ F_d = C_V \cdot F_t \quad (3.47) \]

\[ F_w = \frac{b}{\cos(\gamma_p)} \cdot D_p \cdot Q \cdot K \quad (3.47) \]

\[ Q = \frac{2 \cdot Z_{eq(g)}}{Z_{eq(g)} + Z_{eq(P)}} \quad (3.48) \]

\[ Z_g = Z_p \cdot i \]

\[ Z_{eq(P)} = \frac{Z_p}{\cos(\gamma_p)} \]

\[ Z_{eq(g)} = \frac{Z_g}{\cos(90 - \gamma_p)} \]
Where:
\[ \gamma_p = \text{Con angle} \]

### 3.6 Theoretical field capacity of the machine

Theoretical field capacity of machine \( C_{th} \) on area basis

\[ C_{th} = \frac{B_m \times V_m}{10} \]  \hspace{1cm} (3.54)

Where \( B_m \) width of the machine (m), \( V_m \) travel speed of machine km/h

Total feed rate of tubers \( Q_t \):

\[ Q_t = \frac{B_m \times V_m \times P}{10} \]  \hspace{1cm} (3.55)

Where \( P \) is the production of potato tubers (kg/ha)

### 3.7 Selection of tiers

**Dimensions of Tires**

Dimensions of tiers can be defined by the following equations

\[ Q_x = 0.86^3 \sqrt[3]{\frac{Q_z^4}{qD^2b}} \]  \hspace{1cm} (3.56)

Where \( Q_z \) is the vertical load, Kg, \( Q_x \) is the pull load resistance Kg, \( q \) Volumetric coefficient \( \frac{kg}{m^3} \), \( D \) diameter of tier, \( b \) width of tier.

\[ \frac{Q_x}{Q_z} = \mu \]

\[ \mu = 3 \sqrt[3]{\frac{Q_z}{qD^2b}} \]  \hspace{1cm} (3.57)

Where \( \mu \) is

### 3.8 Power requirement

#### 3.8.1 Power of cutting soil

Power requirement to cut and lift soil

\[ R_{Gs} = a \times b \times \rho_{soil} \times \tan(\alpha + \phi) \]

Wherein \( a, b \) dimensions of soil layer, \( a \) depth of layer, \( b \) width of layer.
Power requirements for cutting soil $P_c$,

$$P_c = R_G s \times v_{\text{travel}}$$

Where $v_{\text{travel}}$ is the travel speed of the machine.

### 3.8.2 Rotary power of the separator

Rotary power selected by calculated the soil load acting on the separator times the velocity of the separator.
CHAPTER FOUR

Design of digger harvester
4. Design of digger harvester

In the previous chapter we discussed the theory of design parameters for potato – digger harvester. In this chapter we are going to calculate the mechanical parts of the proposed machine.

4.1 Calculation of the digger parts

In Sudan the potato tubers maturation occurs at depth $H = 25\text{cm}$ and we will assume clearance $\Delta = 5\text{cm}$ and substitute in equation (3.1).

Angle of inclination from the horizontal $\alpha$ can be calculated by using equation (3.2)

$$\alpha \leq 90 - 22$$

From previous studies we will take $\alpha = 40^\circ$.

$$l_D = \frac{25 + 5}{\sin 40}$$

$$l_D = 46.67\text{cm}$$

Let assume

The number of notches $n = 9$,

Clearance between notches $s$ must be less than diameter of potato $d_p$

$$s < d_p$$

From table (4.1) we selected the least dimensions (group 1), thus:

$d_p = \sqrt[3]{38 \times 37 \times 29}$

$d_p = 34.42 \approx 34.5 \text{ mm}$

Taken $s = 200 \text{ mm} = 2\text{cm}$, width of the digger $B_d = 90 \text{ cm}$

Substituting in equation (3.4)

$$90 = 9 \times 2 + 9 \times b$$

$$b = 8 \text{ cm}$$

Table (4.1): dimensions of potato tubers

| Group No. | Tuber Weight (M) gm. | Tuber Length (L) mm. | Tuber Width (W) mm. | Tuber Thickness (H) mm. |
4.1.1 Mechanical design of digger

To determine the load affected on digger blade. First, volume of the soil in the digger.

\[ V_{soil} = A \times H \]

Where \( A \) is the total area of the digger

\[ V_{soil} = 0.9 \times 0.47 \times 0.25 = 0.12 \; \text{m}^3 \]

Weight of the soil on the digger

\[ W_{soil} = m_{soil} \times g \]

\[ m_{soil} = \rho_{soil} \times V_{soil} \]

\[ m_{soil} = 2300 \times 0.12 \]

\[ m_{soil} = 276 \; \text{Kg} \]

\[ W_{soil} = 276 \times 9.81 \]

\[ W_{soil} = 2707.6 \; \text{N} \]

For more safety we applied safety factor \( s_y = 3 \)

\[ W_{soil} = 2707.6 \times 3 = 8122.7 \; \text{N} \]

Thus, moment affected on blade

\[ M = 8122.7 \times 0.45 = 3655.2 \; \text{N} \cdot \text{m} \]

In most potatoes (digger) harvesters the blade material used C1118 and it has yield stress \( \sigma_y = 317 \; \text{MPa} \) see appendix (4.1).

To determine the thickness of digger blade \( t \)

Bending moment on digger blade \( M = \) Maximum bending moment

\[ M = \frac{\sigma_y \times B_d \times t^2}{6} \]

\[ 3655.2 = \frac{317 \times 10^6 \times 0.9 \times t^2}{6} \]

\[ t = 9 \; \text{mm} \]
4.1.2 Selection of screw

We have selection C1020 as a material has yield strength \( \sigma_y = \sigma_t = 289 \text{ Mpa} \).

When a tensile load subjected to bolt from equation (3.5)

\[
P = \frac{\pi}{4} d_c^2 \times \sigma_t
\]

\[
dc = \sqrt{\frac{4P}{\pi \sigma_t}}
\]

\[
dc = \sqrt{\frac{4 \times 8122.2}{\pi \times 289 \times 10^6}}
\]

\[
dc = 6 \text{ mm}
\]

Selecting elevator bolt as joint between digger plate and machine body

The standard dimensions for this bolt \((7.9 \times 19.05) \text{ mm} \) \[1\]

4.2 Design of the separator

4.2.1 Design of separator rods

As shown in fig.(3.2) the diameter of rods \( d_r \) and clearance between the rods \( S_r \) can be calculated by the following:

From table (4.1) we selected the least dimensions (group 1), thus:

\[
d_p = \sqrt[3]{38 \times 37 \times 29}
\]

\[
d_p = 34.42 \approx 34.5 \text{ mm}
\]

Assume \( S_r = 45 \text{ mm} \), Substitute in

\[
S_r - d_r \leq d_p
\]

\[
45 - d_r \leq 34.5
\]

\[
d_r = 10.5 \approx 10 \text{ mm}
\]

This part of machine divided to two separator that to obtain a high separation efficiency.

4.2.2 Design of first separator

To find the angle of inclination of first separator \( \alpha_{s_1} \) depended on coefficient of friction between material separator and soil \( \phi_I \) it must:

\[
\tan \alpha_s < \tan \phi_I
\]

Where \( \phi_I = 22 \)

\[
\tan \alpha_s < 0.4
\]
\[ \alpha_s \leq 22 \]

So we talk \( \alpha_s = 20 \)

### 4.2.2.1 Design of elliptical pulleys

So as we know in a previous chapter to select the dimensions elliptical pulleys. Let assume

- Maximum pulley radius \( r_2 = 11 \text{ cm} \)
- Minimum pulley radius \( r_1 = 7 \text{ cm} \)

and

\[ m = \frac{11}{7} = 1.57 \]

Mean radius of elliptical pulley

\[ = \sqrt{\frac{r_1^2 + r_2^2}{2}} = \sqrt{\frac{0.07^2 + 0.11^2}{2}} = 0.09 \text{ m} \]

From equation \( \beta = 90 + \alpha_s \)

\[ \beta_1 = 90^\circ + 20^\circ = 110^\circ \]

To get a proper extraction

\[ \beta_2 < 110 \]

\[ \sin \beta_2 = \frac{7}{11} \]

\[ \beta_2 = 40 \]

To obtain the typical length for a high soil separation

\[ L = \frac{v_z^2}{g(f \cos \alpha_s - \sin \alpha_s)} \]

\[ L = \frac{2.5^2}{9.81(0.47 \cos 22 - \sin 22)} \]

\[ L = 10.4 \text{ m} \]

So we take \( L = 1.4 \text{ m} \)

### 4.2.2.2 Design of v-belt
We will take diameter of circular pulley is equal to the mean diameter of elliptical pulley.

The diameter of pulley is equal 0.18 m, so standard V-belt is Row-edge narrow DIN section has to be XPC

So calculated the centre distance C

\[ d_1 < C < 3(d_1 + d_2) \]

\[ 0.18 < C < 3(0.18 + 0.18) \]

\[ 0.224 < C < 1.344 \]

Choosing \( C = 1.0439 \) m

Pitch Length of the belt:

\[ L = 2C + 1.57(d_1 + d_2) + \frac{(d_1 - d_2)^2}{4C} \]

\[ L = 2 \times 1043.9 + 1.57(180 \times 2) \]

\[ L = 2653 \text{ mm} \]

From appendix (4.2) \( \Delta_e = 27 \text{ mm} \), So external length of belt \( L_e = 2680 \text{ mm} \) and from appendix (4.3) code of belt XPC 2650 which has Width= 22 mm, thickness= 17 mm

The corrected rated power per belt and the number of belts required to carry the design power:

\[ P_a = (P_b + P_d) \times C \gamma \times C_L \]

Where

\( P_a \) is the allowable power, per belt, \( C \gamma \) is the angle-of-wrap correction factor, \( C_L \) belt length correction factor.

Since \( i = 1 \)

This configuration corresponds to 180° arc of contact belt on both pulleys.

By interpolation from appendix (4.3) we found the allowable power per belt \( P_a \)

\[ \frac{4.22 - 2.68}{P_a - 2.68} = \frac{300 - 200}{265 - 200} \]

\[ P_a = 3.68KW \]

\[ P_d = P_{nom} \times K_s \]

Where

\( P_{nom} \) is the nominal power KW, \( K_s \) is the service factor depended on daily operational hours given in Table(), \( K_s = 1.2 \)
\[ P_d = 9 \times 1.2 \]
\[ P_d = 11 \text{ KW} \]

The number of belts, \( N_b \)

\[ N_b = \frac{P_d}{P_a} \]
\[ N_b = \frac{11}{3.68} = 2.989 \approx 3 \]

So we need three belts to transform the power.

### 4.2.2.3 Design of first shaft

Total load affected on the shafts \( W \)

\[ W = W_{soil} + W_{pulley} \]

Load affected by soil \( W_{soil} \) could measure by the following:

Thickness of the soil on the separator \( Z \)

\[ Z = 0.57H - 0.01 \]
\[ Z = 0.57 \times 0.25 - 0.01 \]
\[ Z = 0.1325 \text{m} \]

Volume of soil on a separator it considered in particular moment in case of stillness

\[ V = l_{s1} \times B_d \times Z \]
\[ V = 1.4 \times 0.9 \times 0.1325 \]
\[ V = 0.167 \text{m}^3 \]

The mass of the soil \( M \)

\[ M = V \times \rho_{soil} \]
\[ M = 0.167 \times 2300 \]
\[ M = 384.1 \text{Kg} \]

Converted mass to load \( (N) \)

\[ W_{soil} = Mg \]
\[ W_{soil} = 384.1 \times 9.81 \]
\[ W_{soil} = 3768 \text{N} \]
For more safety we applied safety factor $s_y = 2$

$$W_{soil} = 7536 \, N$$

The load of each v-belt pulley $W_{pv}$

$$W_{pv} = 3 \times V_{pv} \times \rho_p \times g$$

$$W_{pv} = 3 \times \frac{\pi}{4} \times 0.18^2 \times 0.22 \times 7861 \times 9.81 = 130 \, N$$

The number 3, since the pulley has three grooves

Where $V_{pv}$ is volume of each groove, $\rho_p$ is the density of the material used

The load of each flat-belt pulley $W_{fp}$

$$W_{fp} = \frac{\pi}{4} \times 0.18^2 \times 0.0625 \times 7861 \times 9.81 = 122.6 \, N$$

The first separator is operating by three shafts, so the radial load affected by the soil divided to three shafts, thus the load of soil for each shaft is equal to $\frac{W_{soil}}{3} = 2512 \, N$.

As shown in figure (4.1), rotating shaft subjected to combined twisting and bending moments.

![Fig.4.1: idle (first) shaft of separator 1](image)

The loads of soils and pulleys are vertical loads, where tensions loads of pulleys are horizontal loads.

Vertical loads acting on the shaft

Load of soil $= 2512 \, N$

Load of each flat pulley $= 122.6 \, N$

Let $R_{AV}$ and $R_{BV}$ be the reactions at the bearings A and B respectively relative to vertical direction. We know that

$$R_{AV} + R_{BV} = 2512 + 122.6 \times 2 = 2757.2 \, N$$
Taking moments about A,

\[ R_{BV} \times 1 = 122.6 \times 0.95 + 2512 \times 0.5 + 122.5 \times 0.05 \]

\[ R_{BV} = 1378.6 \, N \]

\[ R_{AV} = 2757.2 - 1378.6 = 1378.6 \, N \]

We know that bending moment (B.M) at any point in fig.(4.1),

B. M at A, \[ M_{AV} = 122.6 \times 0.05 + 2512 \times 0.5 + 122.6 \times 0.95 - 2757.2 \times 1 = \]
\[ = 1378.6 \, N.m \]

B. M at B, \[ M_{BV} = M_{AV} = 1378.6 \, N.m \]

B. M at C, \[ M_{CV} = 2757.2 \times 0.95 - 1226 \times 0.9 - 2512 \times 0.45 = 1240 \, N.m \]

B. M at D, \[ M_{DV} = 2757.2 \times 0.5 - 122.6 \times 0.45 + 122.6 \times 0.45 - 2757.2 \times 0.5 = \]
\[ = 0 \, N.m \]

B. M at E, \[ M_{EV} = M_{CV} = 1240 \, N.m \]

Now considering horizontal loading at C and E. Let \( R_{AH} \) and \( R_{BH} \) be the reactions on the bearing A and B respectively. We know that the load in each pulley is equal to summation of tight and slack tensions.

The PTO power requirement to operate the sieve is equal to 11 KW. So tensions in each pulley

\[ P = (T_1 - T_2 ) \, v_s, \]
\[ 11000 = (T_1 - T_2 ) \, 2.5 \]
\[ T_1 - T_2 = 4400N \] (*)

\[ \frac{T_1}{T_2} = e^{\mu \theta} \]

From table , for the belt and pulley selected, \( \mu = 0.3 \)

\[ \frac{T_1}{T_2} = e^{0.3 \times 3.14} = 2.6 \] (**)

By solving equations (*) and (**)

\[ T_1 = 7150 \, N \]
\[ T_2 = 2750 \, N \]

So load acting on C, E is equal to

\[ T_1 + T_2 = 7150 + 2750 = 9900 \, N \]

\[ R_{AH} + R_{BH} = 19800 \, N \]

55
Taking moment about A,

\[ R_{BH} \times 1 = 5400 \times 0.95 + 5400 \times 0.05 \]
\[ R_{BH} = 9900 \text{ N}, \quad R_{AH} = 9900\text{N} \]

We know that B. M at any point,

B. M at A \[ M_{AH} = 9900 \times 0.05 + 9900 \times 0.95 - 9900 \times 1 = 0 \text{ N.m} \]

B. M at B \[ M_{BH} = M_{AH} = 0 \]

B. M at C \[ M_{CH} = 9900 \times 0.95 - 9900 \times 0.9 - 9900 \times 0.05 = 0 \text{ N.m} \]

B. M at E \[ M_{EH} = M_{CH} = 0 \text{ N.m} \]

Resultant B. M at C,

\[ M_C = \sqrt{M_{CV}^2 + M_{CH}^2} = \sqrt{0^2 + 1240^2} = 1240 \text{ N.m} \]

and Resultant B. M at E

\[ M_E = \sqrt{M_{EV}^2 + M_{EH}^2} = \sqrt{0^2 + 1240^2} = 1240 \text{ N.m} \]

We see that bending moment is maximum in C and E

Maximum bending moment

\[ M = M_{AV} = M_{BV} = 1378.6 \text{ N.m} \]

We took C1045 as a material has yield stress \( \sigma_y = 407 \text{ MPa} \)

\[ \tau_{\text{max}} = 0.6 \sigma_y \]

\[ \tau_{\text{max}} = 0.6 \times 407 = 244.2 \text{ MPa} \]

And from table (4.2). Let’s take \( K_b = 1.5, K_t = 1.5 \)

**Table (4.2): illustrated combined shock and fatigue factor applied to bending and torsional moments**

<table>
<thead>
<tr>
<th></th>
<th>( k_b )</th>
<th>( k_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>load gradually applied</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>load suddenly applied (minor shock)</td>
<td>1.5-2.0</td>
<td>1.0-1.5</td>
</tr>
<tr>
<td>load suddenly applied (heavy shock)</td>
<td>2.0-3.0</td>
<td>1.5-3.0</td>
</tr>
</tbody>
</table>

**Source: Design of machine elements**

\[ \sqrt{(MK_b)^2 + (TK_t)^2} = \frac{\pi}{16} \times \tau_{\text{max}} \times d^3 \]
\[ \sqrt{(1378.6 \times 1.5)^2 + (396 \times 1.5)^2} = \frac{\pi}{16} \times 244.2 \times 10^6 \times d^3 \]

d = 0.035 m = 35 mm

Since available standard shaft diameter \( d = 35 \) mm.

4.2.2.4 Selection of bearing of first shaft

From equation (3.36)

\[ L_{life} = (h)(N)(60 \text{ min/hr}) \]

\[ L_{life} = (3000)(265)(60 \text{ min/hr}) \]

\[ L_{life} = 4770 \times 10^4 \text{ rev} \]

From equation (3.35) the required \( C \) for given design load and life would be

\[ C = 9900\left(\frac{477 \times 10^4}{10^6}\right)^{\frac{1}{3}} \]

\[ C = 16665.1 \text{ N} \]

From table (4.3) at shaft diameter \( d = 35 \) mm, dynamic load rating \( C = 19500 \) we found the bearing designation is 6206 which it has outer diameter \( D = 80 \) mm, and axial width \( B = 17 \) mm.

Table 4.3: Dimensions and static and dynamic load capacities of single –row deep groove ball bearings

<table>
<thead>
<tr>
<th>Principle dimensions (mm)</th>
<th>basic load rating (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>D</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Designation</strong></td>
<td>( 25 )</td>
</tr>
<tr>
<td><strong>d</strong></td>
<td>37</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>7</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>7</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>312</td>
</tr>
<tr>
<td><strong>( C_0 )</strong></td>
<td>1960</td>
</tr>
<tr>
<td><strong>d</strong></td>
<td>42</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>7</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>9</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>3120</td>
</tr>
<tr>
<td><strong>( C_0 )</strong></td>
<td>2080</td>
</tr>
</tbody>
</table>

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4.2.2.5 Selection of key and key seat of first shaft

The required length of key

\[ L_k = \frac{4TN}{DWs_y} \]

From appendix (4.6) \( w = 9.5 \text{mm}, H = 9.5 \text{mm} \)

We use C1010 (K) as a material which has \( s_y = 379M \)

\[ L_k = \frac{4 \times 396 \times 3}{0.035 \times 9.5 \times 10^{-3} \times 379 \times 10^6} \]

\[ L_k = 0.0377m = 37.7 \text{m} \]

Key seat

Chordal height from equation (3.32)
\[ Y = \frac{0.035 - \sqrt{0.035^2 - 0.0095^2}}{2} \]
\[ Y = 6.6 \times 10^{-4} \text{m} = 0.65 \text{mm} \]

**Depth of shaft key seat** from equation (3.33)

\[ S = D - Y - \frac{H}{2} \]
\[ S = 0.035 - 6.6 \times 10^{-4} - \frac{0.0095}{2} \]
\[ S = 0.03 \text{m} = 30 \text{mm} \]
**Depth of hub key seat** from equation (3.34)

\[
T = 0.035 - 6.6 \times 10^{-4} + \frac{0.0095}{2} + 0.127 \times 10^{-3}
\]

\[
T = 0.039m = 39 \text{ mm}
\]

### 4.2.2.6 Design of main shaft

As shown in figure (4.2), rotating shaft subjected to combined twisting and bending moment.

![Fig.4.2: main drive shaft](image)

The loads of soils and pulleys are vertical loads, where tensions loads of pulleys are horizontal loads.

- Vertical loads acting on the shaft
  - Load of soil = 2512 N
  - Load of each V-Belt pulleys = 130 N
  - Load of each flat-Belt pulleys = 122.6 N

#### 4.2.2.7 Selection of gears

First, we found circular pitch of gear \( P_c \) is equal to 22 mm

\[
P_c = 22 \text{ mm}
\]

\[
P_c = \frac{\pi d}{T}
\]

Since the diameter of gear is equal the diameter of pulleys, \( d = 180 \text{ mm} \)

\[
22 = \frac{\pi \times 180}{T}
\]

\[
T = 26 \text{ Teeth}
\]

Thus, module of two gears, \( m \)

\[
m = \frac{d}{T}
\]

\[
m = \frac{180}{26} = 7
\]

**Dimensions of gears**

- Pressure angle = 20°
- Addendum = \( m = 7 \text{ mm} \)
- Dedendum = 1.25 \( m = 8.75 \text{ mm} \)
Working depth ≤ 2m = 14 mm
Whole depth = 2.25m = 15.75 mm
Clearance = 0.25m = 1.75
Width of top land ≤ 0.25m = 1.25 mm (min

**Loads on gears**

From a previous chapter the tangential load acting on the gear tooth,

\[ P_t = \frac{2T}{d} \]

\[ P_t = \frac{2 \times 396}{180} \]

\[ P_t = 4400 \text{ mm} \]

and the radial load

\[ P_r = \frac{P_t}{\cos 20^\circ} \]

\[ P_r = \frac{4400}{\cos 20^\circ} \]

\[ P_r = 4682.4 \text{ N} \]

**Load of gear**

\[ W_{gear} = \frac{\pi}{4} \times 0.18^2 \times 0.0625 \times 7861 \times 9.81 = 127.6 \text{ mm} \]

Load of each gears = 127.6 + 468.24 = 4810

Let \( R_{AV} \) and \( R_{BV} \) be the reactions at the bearings A and B respectively relative to vertical direction. We know that

\[ R_{AV} + R_{BV} = 2512 + 122.6 \times 2 + 130 \times 2 + 4810 \times 2 = 12637.2 \text{ N} \]

Taking moments about A,

\[ R_{BV} \times 1 = 130 \times 1.05 + 122.6 \times 0.95 + 4810 \times 0.9 + 2512 \times 0.5 + \]

\[ 4682 \times 0.1 + 122.5 \times 0.05 + 130 \times 0.05 \]

\[ R_{BV} = 6319 \text{ N} \]

\[ R_{AV} = 6319 \text{ N} \]

We know that bending moment (B.M) at,

B.M at A \[ M_{AV} = 130 \times 0.05 - 122.6 \times 0.05 - 4810 \times 0.1 - 2512 \times 0.5 - \]

\[ 4810 \times 0.9 - 122.6 \times 0.95 - 130 \times 1.05 = \]

\[ = 1736.63 \text{ N.m} (-) \]

B.M at B \[ M_{BV} = M_{AV} = 1736.63 \text{ N.m} \]

B.M at C \[ M_{CV} = 130 \times 1 - 6319 \times 0.95 + 122.6 \times 0.9 + 4810 \times 0.85 + \]

\[ 2512 \times 0.45 + 4810 \times 0.05 + 6319 \times 0.05 - 130 \times 0.1 = \]

\[ = 1192 \text{ N.m} (-) \]
B.M at D, \[ M_{DV} = 130 \times 0.55 - 6319 \times 0.5 + 122.6 \times 0.85 + \\
4810 \times 0.8 + 2512 \times 0.4 - 122.6 \times 0.05 + 6319 \times 0.1 - \\
130 \times 0.15 = 1611 \, N.m(-) \]

B.M at E, \[ M_{EV} = 130 \times 0.55 - 6319 \times 0.5 + 122.6 \times 0.45 + 4810 \times 0.4 = \\
= 1108.38 \, N.m(-) \]

B.M at F, \[ M_{FV} = M_{DV} = 1611 \, N.m(-) \]

B.M at G, \[ M_{GV} = M_{CV} = 1192 \, N.m(-) \]

B.M at H, \[ M_{HV} = 130 \times 1.1 - 6319 \times 1.05 + 122.6 \times 1 + 4810 \times 0.95 + \\
2512 \times 0.55 + 4810 \times 0.15 + 122.6 \times 0.1 - 6319 \times 0.05 = \\
= 1049.71 \, N.m \]

B.M at I, \[ M_{IV} = M_{HV} = 1049.71 \, N.m \]

Now considering horizontal loading at C, D, F, G and H. Let \( R_{AH} \) and \( R_{BH} \) be the reactions on the bearing A and B respectively. We know that the load in each pulley is equal to summation of tight and slack tensions.

\[ T_1 = 7150 \, N \]
\[ T_2 = 2750 \, N \]

So load acting on C, G, and H is equal to \( T_1 + T_2 \)

\[ = 7150 + 2750 = 9900 \, N \]
\[ R_{AH} + R_{BH} = 38500 \, N \]

Taking moment about A,

\[ R_{BH} \times 1 = 9900 \times 0.95 + 4400 \times 0.9 + 4400 \times 0.1 + 9900 \times 0.05 - 9900 \times 0.05 = 14300 \, N \]
\[ R_{BH} = 13805 \, N \]
\[ R_{AH} = 24200 \, N \]

We know that

B.M at A \[ M_{AH} = 9900 \times 0.05 - 9900 \times 0.05 - 4400 \times 0.1 - 400 \times 0.9 - \\
9900 \times 0.95 + 13805 \times 1 = 0 \, N.m \]

B.M at B \[ M_{BH} = 9900 \times 1.05 - 25695 \times 1 + 9900 \times 0.95 + 4400 \times \\
0.9 + 44000.1 + 9900 \times 0.05 = 1000 \, N.m(-) \]

B.M at C \[ M_{CH} = 9900 \times 1 - 25695 \times 0.95 + 9900 \times 0.9 + 4400 \times 0.85 + \\
4400 \times 0.05 + 13805 \times 0.05 = 950 \, N.m(-) \]

B.M at D \[ M_{DH} = 9900 \times 0.95 - 25695 \times 0.9 + 9900 \times 0.85 + 4400 \times \\
0.8 - 9900 \times 0.05 + 13805 \times 0.1 = 900 \, N.m(-) \]

B.M at G \[ M_{GH} = 9900 \times 0.1 - 25695 \times 0.05 - 4400 \times 0.05 - 4400 \times 0.85 - \\
9900 \times 0.9 + 9900 \times 1 = 50 \, N.m(-) \]

B.M at F \[ M_{FH} = 9900 \times 0.15 - 25695 \times 0.1 + 9900 \times 0.05 - 4400 \times 0.8 - \\
9900 \times 0.85 + 13805 \times 0.9 = 50 \, N.m \]

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B. M at H

\[ M_{HH} = 25695 \times 0.05 - 9900 \times 0.1 - 4400 \times 0.15 - 4400 \times 0.95 - 9900 \times 1 + 13805 \times 1.05 = 50 \, N.m \]

The bending moment diagram for horizontal loading is shown in Fig.()

Resultant B. M at C, D, F and G

\[
\begin{align*}
M_C &= \sqrt{M_{CV}^2 + M_{CH}^2} = \sqrt{1192^2 + 950^2} = 1524.3 \, N.m \\
M_D &= \sqrt{M_{DV}^2 + M_{DH}^2} = \sqrt{1611^2 + 900^2} = 1845.4 \, N.m \\
M_F &= \sqrt{M_{FV}^2 + M_{FH}^2} = \sqrt{1611^2 + 100^2} = 1614.1 \, N.m \\
M_G &= \sqrt{M_{GV}^2 + M_{GH}^2} = \sqrt{1192^2 + 50^2} = 1193 \, N.m
\end{align*}
\]

We see that bending moment is maximum at C

Maximum bending moment,

\[ M = M_C = 601.5 \, N.m \]

We took C1045 as a material has yield stress \( \sigma_y = 407 \, MPa \)

\[ \tau_{max} = 0.6 \, \sigma_y \]

\[ \tau_{max} = 0.6 \times 407 = 244.2 \, MPa \]

And from table (4.2). Let’s take \( K_b = 1.5, \, K_t = 1.5 \)

\[
\sqrt{(MK_b)^2 + (TK_t)^2} = \frac{\pi}{16} \times \tau_{max} \times d^3
\]

\[
\sqrt{(1845.4 \times 1.5)^2 + (396 \times 1.5)^2} = \frac{\pi}{16} \times 244.2 \times 10^6 \times d^3
\]

\[ d = 0.039 \, m = 39 \, mm \approx 40 \, mm \]

4.2.2.8 Selection of bearing for main shaft

From equation (3.36) the required C for a given design load and life would be

\[
L_{life} = (3000)(265)(60 \, min/hr) \]

\[ L_{life} = 4770 \times 10^4 \, rev \]

\[ C = 13805\left(\frac{4770 \times 10^4}{10^6}\right)^{\frac{1}{3}} \]

\[ C = 50066 \, N \]

From table (4.3) at shaft diameter \( d = 40 \, mm \), dynamic load rating \( C = 63700 \) we found the bearing designation is 6408 which has outer diameter

\[ D = 110 \, mm, \, and \, axial \, width \, B = 27 \, mm. \]
4.2.2.9 Selection of key and key seat

From table (4.6) \( w = 9.5 \text{ mm}, H = 9.5 \text{ mm} \)

The required length of key

We use C1010(K) as a material which has \( S_y = 379 \text{ MPa} \)

\[
L_k = \frac{4 \times 396 \times 3}{0.04 \times 0.0095 \times 379 \times 10^6}
\]

\[
L_k = 33 \times 10^{-3} \text{ m} = 33 \text{ mm}
\]

**Key seat**

**Chordal height** from equation (3.32)

\[
Y = \frac{0.04 - \sqrt{0.04 - 0.0095^2}}{2}
\]

\[
Y = 5.7 \times 10^{-4} \text{ m} = 0.57 \text{ mm}
\]

**Depth of shaft key seat** from equation (3.33)

\[
S = D - Y - \frac{H}{2}
\]

\[
S = 0.04 - 5.7 \times 10^{-4} - \frac{0.0095}{2}
\]

\[
S = 0.035 \text{ m} = 35 \text{ mm}
\]

**Depth of hub key seat** from equation (3.34)

\[
T = 0.04 - 5.7 \times 10^{-4} + \frac{0.0095}{2} + 0.127 \times 10^{-3}
\]

\[
T = 0.044 \text{ m} = 44 \text{ mm}
\]

4.3 Design of Second separator

From researches as showed in previous chapter we can select \( v_2 = 1.2 \text{ m/s} \)

\[
v_2 = \frac{\pi DN_2}{60}
\]

Choosing \( N_2 = 100 \text{ rpm} \), So diameter of v-belt pulley

\[
1.2 = \frac{\pi \times 100 \times D}{60}
\]

\[
D = 0.23 \text{ m}
\]

We can take the same values diameters of shafts for diameters of the shafts and bearing and keys and key seat.

4.3.1 Length of belt drive

Pulleys have diameters \( d, D \), so the nominal range of center distances should be:

\[
d_2 < C < 3(d_2 + d_3)
\]
Selection $C = 0.93$

\[
L = 2C + 1.57(d_1 + d_2) + \frac{(d_1 - d_2)^2}{4C}
\]

\[
L = 2 \times 930 + 1.57(230 + 180) + \frac{(230 - 180)^2}{4 \times 930}
\]

$L = 2503 \text{ mm}$

\[
\theta = 180^\circ - 57 \times \frac{d-d}{l_e}
\]

\[
\theta = 180^\circ - 57 \times \frac{230-180}{2830}
\]

\[
\theta = 178^\circ
\]

So

\[
5500 = (T_1 - T_2) \times 1.8
\]

\[
(T_1 - T_2) = 5500 \text{ N}
\]

\[
\frac{T_1}{T_2} = e^{\mu \theta}
\]

\[
\frac{T_1}{T_2} = e^{0.3 \times 3.1} = 2.5
\]

$T_1 = 9166.67 \text{ N}, T_2 = 3666.67 \text{ N}$

To selection belt section we will take the same procedures submitted in first separator the corrected rated power per belt and the number of belts required to carry the design power:

\[
P_a = (P_b + P_d) \times C\gamma \times C_L
\]

From appendix (4.4) $C_L = 0.96$ and from table (4.5) $C\gamma = 0.99$

$P_b = 2.2 \text{ KW} \quad P_d = 0.12 \text{ KW}$

\[
P_a = (2.2 + 0.12) \times 0.99 \times 0.96
\]

\[
P_a = 2.2 \text{ KW}
\]

Usually the efficiency of separation in the first separator is 85%.

So the power requirement for the second separator will reduced to half (5.5 KW).

The number of belts, $N_b$

\[
N_b = \frac{5.5}{2.2} = 2.5 \approx 3
\]

So we need three belts to transform the power.

4.4 Selection of Tiers

Dimensions of Tires

As shown in figure (4.3) we can selected diameter and width of tiers by knowing coefficient of volume compressibility $q$, slippage coefficient $\mu$ and weight of the machine $Q_z$. 

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Where \( q = 1.1 \text{ Kg/cm}^3 \), \( \mu = 0.15 \) and \( Q_z = 400 \text{ Kg} \)

![Diagram of soil and tiers dimensions](image)

**Fig. (4.3): illustrate relation between soil and tiers dimensions**

At \( b_t = 18 \text{ cm} \), we found \( D_t = 75 \text{ cm} \).

### 4.5 Selection of gearbox

\[
N_{in} = 540 \text{ rpm} \\
N_{out} = 265 \text{ rpm}
\]

\[ i = 2.0377 \]

Assumption (1):
\[ Z_p = 19 \text{ Teeth} \]
\[ m = 3.75 \]
Material C1060 \[ \sigma_y = 813 \text{ MPa} \]
\[ \phi = 20^\circ \text{ FD} \]
From equation (3.45):
\[ \gamma_p = 29^\circ \]
\[ T = 194527.7 \text{ N.mm} \]
\[ Z_{eq(P)} = 21.16 \]
\[ D_P = 71.25 \text{ mm} \]
\[ L = 80.977 \text{ mm} \]

From equation (3.46):

\[ 20.24 \leq b \leq 26.99 \]

Can be choose:

\[ b = 26.955 \text{ mm} \]
\[ D_m = 58.045 \text{ mm} \]
\[ F_t = 6702.66 \text{ N} \]

S.F = 1.5

\[ F_s = 11476.45 \text{ N} \]
\[ \frac{F_s}{F_t} = 1.72 \]
\[ V = 2.014 \text{ m/sec} \]
\[ C_V = 1.33 \]

From equation (3.48):

\[ Z_g = 39 \text{ Teeth} \]
\[ Z_{eq(g)} = 67.33 \]
\[ Q = 1.522 \]
\[ F_w = 10910 \text{ N} \]
\[ \frac{F_w}{F_d} = 1.22 \]

From above can be design the bevel gear by dimensions:

Material  C 1060

\[ m = 3.75 \]
\[ Z_p = 19 \text{ Teeth} \quad D_p = 71.25 \text{ mm} \]
\[ Z_g = 39 \text{ Teeth} \quad D_g = 145.2 \text{ mm} \]

4.6 calculation theoretical field capacity of the machine

Theoretical field capacity of machine \( C_{th} \) on area basis

\[ C_{th} = \frac{0.9 \times 1.1}{10} = 0.01 \text{ ha/hr} \]

4.7 Some Total Power requirements

4.7.1 Power of cutting soil

Power requirement to cut and lift soil

\[ P_c = R_{CS} \times v_{travel} \]
\[ R_{gs} = a \times b \times \rho_{soil} \times \tan(\alpha + \phi_i) \]

\[ R_{gs} = 0.25 \times 0.9 \times 2300 \times \tan(40 + 22) \]

\[ R_{gs} = 974 \text{ N} \]

\[ P_c = 974 \times 1.1 \]

\[ P_c = 1072 \text{ W} \]

**4.7.2 Rotary power of the separator**

Rotary power selected by calculated the soil load acting on the separator times the velocity of the separator.

To determine this power weight of the soil is 3768N and we took 1.2 as a safety factor multiply by velocity of separator.

\[ P_{rot} = 3768 \times 1.2 \times 2.5 \]

\[ P_{rot} = 11000 \text{ W} \]

---

Potato digger-harvester specifications
<table>
<thead>
<tr>
<th>Description</th>
<th>Parameters</th>
<th>Unit</th>
<th>Parameter values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digger</td>
<td>$L_d$</td>
<td>mm</td>
<td>467</td>
</tr>
<tr>
<td></td>
<td>$B_d$</td>
<td>mm</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>$\alpha$</td>
<td>degree</td>
<td>40°</td>
</tr>
<tr>
<td></td>
<td>$T$</td>
<td>mm</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>$\gamma$</td>
<td>degree</td>
<td>136°</td>
</tr>
<tr>
<td></td>
<td>$b$</td>
<td>mm</td>
<td>80</td>
</tr>
<tr>
<td>Separator 1</td>
<td>$L_{s_1}$</td>
<td>mm</td>
<td>1400</td>
</tr>
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<td>$\alpha_{s_1}$</td>
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<td>22°</td>
</tr>
<tr>
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<td>$v_{s_1}$</td>
<td>m/s</td>
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<tr>
<td>Separator 2</td>
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<td>mm</td>
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<td>$\alpha_{s_2}$</td>
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<tr>
<td></td>
<td>$v_{s_2}$</td>
<td>m/s</td>
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<td>mm</td>
<td>180</td>
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<tr>
<td>Power</td>
<td>$P_c$</td>
<td>W</td>
<td>1072</td>
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<td>$P_{rot.}$</td>
<td>W</td>
<td>11000</td>
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</table>
Figures (4:4) illustrated components, design views and schematic of each element of the machine
### Illustration #1

![Diagram of mechanical components]

### Illustration #2

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Flat belt</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Circular pulley</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Elliptical pulley</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Gear</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Shaft</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Rod</td>
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<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>Digger case</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Digger bolt</td>
<td>18</td>
</tr>
</tbody>
</table>
V-belt
Separator 1#
(front, side and top views)
Separator 2 #
(front, side and top views)
Pulleys
Machine views

(front, side and top views)
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<tr>
<td></td>
<td>$B_d$</td>
<td>mm</td>
<td>900</td>
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<tr>
<td></td>
<td>$\alpha$</td>
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<td>$T$</td>
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<td></td>
<td>$v_{s_1}$</td>
<td>m/s</td>
<td>2.5</td>
</tr>
<tr>
<td>Separator 2</td>
<td>$L_{s_2}$</td>
<td>mm</td>
<td>1200</td>
</tr>
<tr>
<td></td>
<td>$\alpha_{s_2}$</td>
<td>degree</td>
<td>15°</td>
</tr>
<tr>
<td></td>
<td>$v_{s_2}$</td>
<td>m/s</td>
<td>1.8</td>
</tr>
<tr>
<td>Tiers</td>
<td>$D_t$</td>
<td>mm</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>$b_t$</td>
<td>mm</td>
<td>180</td>
</tr>
<tr>
<td>Power</td>
<td>$P_c$</td>
<td>W</td>
<td>1072</td>
</tr>
<tr>
<td>requirements</td>
<td>$P_{rot.}$</td>
<td>W</td>
<td>11000</td>
</tr>
</tbody>
</table>
The Digger

(front, side and top views)
4.8 Conclusion

Design requirements have been determined and found to be:

- Dimensions of the digger

Length 466.7 mm, width of the digger 900 mm, width of notch 80 mm, thickness 9 mm, angle of inclination 40°, number of notches 9, obtuse angle of the notch 136°.

- Separators dimensions and speeds

First separator, length 1.4 m, angle of inclination 22°, speed 2.5 m/s.

Second separator, has a length 1.2 m, angle of inclination 15°, speed 1.8 m/s.

- Dimensions of the separator’s mechanical parts

diameter of the flat belts pulleys 180 mm, diameter of the v-belts pulleys 180 mm for the first separator. And 230 mm for the second separator. Gears module= 7 mm, circular pitch= 22 mm, No. of teeth= 26

- Dimensions of the tire

Tiers width of the tire 180 mm, diameter of tire 800 mm

- Power requirements

Power requirement to cut and lift potato tubers from the soil is 1072 W and the power requirement for sieving and extracting soil by separators is 11000 W.

- Field capacity of the machine $C_{th}$ on area basis= 0.01 ha/hr

4.9 Recommendations

- Designing a hopper at the rear of the harvester.

- Manufacturing.

- Analyse the machine performance in the field.

- Determine economic efficiency.

- Increasing the units of machine to reduce the time of harvesting.
### Table AT7: Typical Properties of Materials

<table>
<thead>
<tr>
<th>Material AISI No.</th>
<th>Condition (s)</th>
<th>Yield, MPa</th>
<th>Elong., % 59 mm</th>
<th>Density, kg/m³</th>
<th>BHN 300</th>
<th>ROCK 50%</th>
<th>IZOD toughness</th>
<th>SOME TYPICAL USES, REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrought iron</td>
<td>As rolled</td>
<td>292</td>
<td>241</td>
<td>7.80</td>
<td>170</td>
<td>137</td>
<td>50</td>
<td>BARS, STICKS, SHEETS, PLATES, SLOTS, RODS, SHAFTS</td>
</tr>
<tr>
<td>Wrought steel</td>
<td></td>
<td>281</td>
<td>344</td>
<td>7.80</td>
<td>137</td>
<td>50</td>
<td>50</td>
<td>BARS, RODS, SHEETS, PLATES, SLOTS, RODS, SHAFTS</td>
</tr>
</tbody>
</table>

### Appendix 4.1: Properties of Different Materials

*Density is about 281 (kg/m³) (7750 kg/m³) for wrought iron.*

*Coefficient of thermal expansion (linear) is 0.0000125 (0.200227 mm/m°C for wrought iron). Variance is significant with large temperature changes. See Table 2.22 for cryogenic applications.*

*Table 2.21: Properties of different materials.*

- **AISI 1010:** Cold drawn 1462 255 25 57 137
- **AISI 1020:** Cold drawn 1730 255 25 57 137
- **AISI 1030:** Cold drawn 1900 255 25 57 137
- **AISI 1040:** Cold drawn 2070 255 25 57 137
- **AISI 1050:** Cold drawn 2240 255 25 57 137
- **AISI 1060:** Cold drawn 2410 255 25 57 137
Appendix 4.3: XPC section and allowable power for belt

Appendix 4.4: Correction factor $C_L$ according to type and length of the belt

Appendix 4.5: Correction factor $C_\gamma$ (T/T=V/V drives; T/P=V/Flat drives; g=arc of contact on the smaller pulley)
Appendix 4.6: Key size vs. shaft diameter

<table>
<thead>
<tr>
<th>Nominal shaft diameter</th>
<th>Nominal key size</th>
<th>Height, $H$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over</td>
<td>To (incl.)</td>
<td>Width, $W$</td>
</tr>
<tr>
<td>5/16</td>
<td>7/16</td>
<td>3/32</td>
</tr>
<tr>
<td>7/16</td>
<td>9/16</td>
<td>1/8</td>
</tr>
<tr>
<td>9/16</td>
<td>7/8</td>
<td>3/16</td>
</tr>
<tr>
<td>7/8</td>
<td>1</td>
<td>1/4</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>5/16</td>
</tr>
<tr>
<td>11/16</td>
<td>1/2</td>
<td>3/8</td>
</tr>
<tr>
<td>13/16</td>
<td>1/2</td>
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<tr>
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</tr>
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