Preliminary considerations in the development of the 'mine - sweeper' - a demining tool with vibrating sieve

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Background

This report arose out of a period that the author spent with Emanuela Cepolina in the PMAR lab of the Department of Mechanics and Machine Design at the University of Genoa in July 2007. That work mainly concerned the development of the Participatory Agricultural Technology (PAT) machine – later known as Disarmadillo.

The work reported here was subsequently done in his own workshop and land near Melbourne. Australia. It was limited to some extent by the components that were to hand but is considered a suitable basis for further experimental work. The author is willing to correspond with anyone who is interested in exploring further developments.

1.0 Introduction

The work reported here is based on the understanding that in many circumstances the removal of anti-personnel land mines can be achieved by under-cutting them with a soil working tool and bringing them to the surface with some type of sieve.

The author is of the opinion that given the wide range of soils, soil conditions and surface plant growth it is likely that there will need to be a range of tool and sieve types to achieve the above objective. One type may be based on the tools that have been developed for dry-land agriculture over many decades and which are likely to operate satisfactorily in a range of conditions.

One form of such a tool is the agricultural 'sweep' shown in Figure 1

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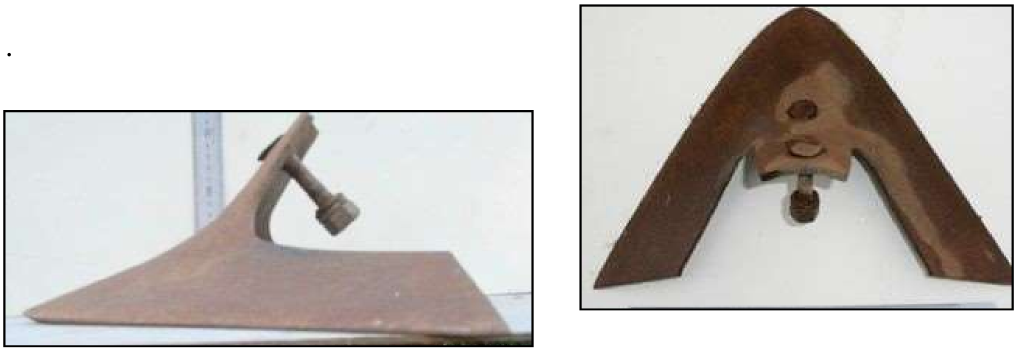


Figure 1: Agricultural sweep (300 mm wide)

Earlier work (Report No 6) reported in January 2011 based on such a tool in a loose Australian loam soil suggested that while the tool would operate satisfactorily, the 'passive' sieve which was rigidly attached to it would not if set at an angle of elevation sufficient to bring the simulated mines to the surface.

The objective of the work reported here was therefore to explore the function of an 'active' (vibrating) sieve operated behind the sweep again operating in a loam soil.

The work should NOT be seen as a the development of a prototype but more as a preliminary exploration in which the important parameters could be varied. These included the speed and direction of the vibration and the elevation angle of the sieve. The amplitude of the vibration could also be changed (albeit less easily) by making an alternative eccentric.

This experimental stage in the development was seen as necessary because of the lack of published material on a vibrating conveying sieve (at least to which the author had access) to guide the design process.

2.0 Description

This tool is based on a conventional agricultural 'sweep' that is used for secondary cultivation, particularly killing weeds in dry-land cereal production. Its shape as shown in Figure 1 enables it to cut and lift the soil and leave it in a broken state. In cutting the soil it also cuts the weed roots or, because of the high lateral stiffness of the tine shank on which it is mounted, it will push the root to one side. This side movement occurs because, in the plan view the sweep has a 'swept back' shape.

The common use of the sweep would be with it fitted to a 'spring release' tine on a cultivator operated by a large tractor. Without the release feature the tractor would damage the tine if the latter hit an immovable object buried in the soil.

The tine which was used in this work was a spring release type but the spring release feature was locked out and the tine operated in an area for which it was known there were no immovable objects. It was quite rigid in the fore and aft and lateral directions.

In normal demining operation with such a demining sweep it would be necessary that all of the tines be rigidly mounted and of sufficient strength to stall the tractor by slipping of the wheels.

The cultivator on which such sweeps would usually be mounted has three or four transverse rows of tines with the sweeps transversely off-set in each successive row. This provides good trash clearance as the tines in each transverse row are two or three tine spacings apart. This is likely to be important for many agricultural areas where trash will be a significant factor and any machine to work in such areas will have to be designed to handle this material.

On the basis of these characteristics it would appear that the sweep could provide a satisfactory soil cutting tool for demining in soils that have trash present. Whether the sweep would require previous soil loosening operation depends on the strength of the soil which in turn will depend on its constituents, moisture content and its previous history of working, if any.

The use of a number of 'small' soil cutting tools such as the present one would allow the number used in any given circumstance to be chosen to suit the capacity of the tractor and draft of the sweeps. Again this will depend on the strength of the soil which in turn will depend on its constituents, moisture content and its previous history of working, if any

The condition of the soil, particularly in terms of particle, ie, crumb and clod size, after the passage of such a sweep will determine the need for sieving and the form of the sieve required. Sandy soils with little structure will be easy to cut and lift and will not form even small, well defined crumbs and clods. Hence they would probably only require a passive sieve.

Soils with a greater proportion of silt and clay and a significant amount of organic matter (normally called 'loams') form strong crumbs and clods often together with a large proportion of fines. These soils will pack easily and will form arches between the fingers of the sieve hence, as reported previously, they will not be easy to sieve in the passive sieve of the type as in the earlier report.

Active sieves are required to sieve such soils and the present work was directed towards developing such a unit to work in conjunction with the sweep described in the previous section.

Various types of sieves have been designed to operate in loam soils and, for example separate root vegetables from the soil bulk and associated clods.

Tools with passive sieves use rods as in the previous report and are usually described as 'lifters'. These may operate satisfactorily in soils used for vegetable growing which is loose and friable.

Other machines with active sieving pass the soil from the full width of the machine through sieve formed by a rising chain of rods rotating within a frame which is itself subject to transverse vibration. The unit separates most of the soil and many of the clods and deposits the remainder with the roots and any unbroken clods on the surface.

In the earlier work a passive sieve in loam soil with a significant amount of fines did not function satisfactorily particularly when the sieve was raised at the rear to allow the fines to pass through the sieve. It formed arches between the fingers and built up behind the sweep and formed a trench by shedding the soil to the side.

The conclusion was that for such soils, which would be common in many agricultural situations, an active sieve would be necessary. The present work therefore had the objective of developing such a sieve to be used on the associated sweep to provide a mine digging tool. The unit would be expected to work in agricultural soils which perhaps had never been cultivated but which had a trash and associated roots. Prior soil loosening may be necessary.

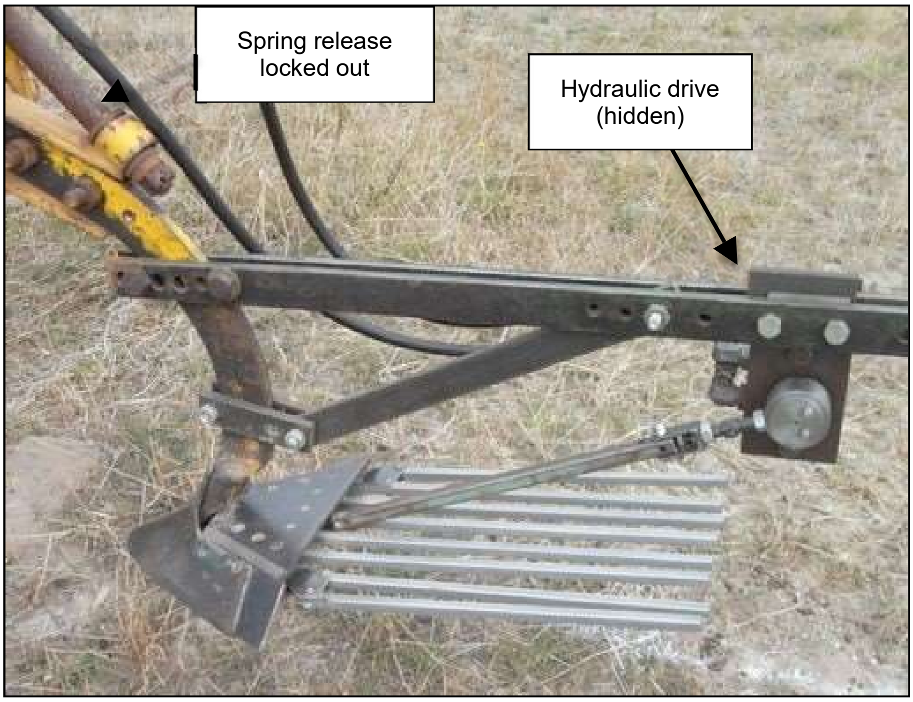


Figure 2: General arrangement of tool mounting and drive.
The bolted mounting was used for ease of adjustment.
The spring release mechanism was locked out.

3.0 Vibrating sieves

The objective was to use a sieve that was vibrated in such a way that, as well as having a sieving action, would also have a conveying action and so help to overcome or at least minimize the problem of the soil being 'bull-dozed' and 'shed' to the side as occurred with the passive tool as reported previously.

Two sources of vibration are possible to drive the sieve.

3.1 Fixed force

Here the sieve would be driven by a pair of rotating eccentrics geared together giving a unidirectional, out-of-balance force. If the sieve was subject to a greater drag force in the direction of motion the amplitude of the sieve would be correspondingly smaller and less well defined. As a source of general vibration to break up the arches on the sieve this may be satisfactory but as a source of vibration to convey the soil and mines rearwards with respect to the sweep, it is likely that it would be less so.

3.2 Fixed amplitude

Here the sieve is driven by an eccentric providing a fixed amplitude vibration. This arrangement allows the direction of the vibration to be more easily controlled and varied in the context of an experimental arrangement. It has the disadvantage that if the vibratory motion was blocked, for example by a stone becoming jammed between the fixed sweep and the vibrating mounting plate, the drive mechanism could be damaged in some way

The fixed amplitude was used here as it is easier to implement in this work and as noted above is more defined than the fixed force arrangement. However in any prototype and production machine a fixed force arrangement might be easier to implement and more reliable.

The throw (double amplitude) of the vibration that was necessary to sieve the soil was not known nor were there precedents for the design of the combined conveyor / sieve, at least to which the author had access. A fixed amplitude of 4 mm was used. The frequency of operation was determined by the hydraulic motor and the tractor as the available source of hydraulic fluid. The maximum frequency was some 200 cycles per minute.

Figure 3: Sweep with cover plate which protects and provides mounting for the sieve

Figure 4: Eccentric drive

4.0 Design arrangements

In developing the tool the objective of the vibratory sieve was to

(i) lift the soil and any enclosed mines

(ii) break up the soil mass

(iii) prevent arching of the soil across the sieve rods

(iv) convey or to assist in conveying the soil the soil rearwards across the sieve

(v) allow the smaller particles to pass through the rods and so leave the larger particles and mines on the soil surface

4.1 Lift the soil and any enclosed mines

The sweep has been designed and has evolved to lift the soil so killing any weeds growing in it. There is inevitably some lateral movement as a result of the passage of the oblique wings and mounting bracket but this is minimal and does not require any post cultivation leveling. It is possible that there will be some vertical segregation (sorting) of the soil particles according to their size with the smallest ('crumbs') on the bottom and clods, lumps etc higher up. The latter is likely to include any mines but they may still not be visible.

4.2 Break up of the soil mass

The extent to which this occurs will depend on several interacting factors including the soil texture (basic particles), structure (agglomerations), the history of previous disturbances, the presence of plants, roots etc. Moisture content will also be a significant factor in the lifting and breaking processes hence there may be an optimum period during which the processes should be undertaken. Mines are not likely to hinder the break up of the mass.

A factor which is associated with this process will be the draft of the tool which in turn will determine the size of the machine that can be pulled by the operating tractor. A pre-ripping may be necessary or desirable - a process which is likely to greatly assist in the lifting and sieving processes.

4.3 Prevent arching across rods

The arching of granular materials like soil is a common feature during their gravity flow. It is caused by the mass of particles gaining enough strength during compaction which inevitably occurs to form a stable arch. Increasing the width of the space through which the material is flowing will prevent the arching but this is not possible in the present work where the width of the space between the rods must be less than the minimum dimension of the mines.

In the present context the prevention of arching is only likely to be achieved with vibration as well as the motion associated with the conveying the soil along the sieve (see on). It was thought that the vibration associated with the latter motion would also be satisfactory to disturb the soil mass and so prevent the arching particularly of the smaller particles which prevents the sieving action. This will, in turn, avoid the build up on the sieve and minimize any sideways shedding of the soil.

4.4 Convey soil rearwards

The problem with the passive sieve was that when its rear was raised to lift the mines, the soil did not pass through the sieve but was shed to the sides leaving a trench. Mines would not necessarily have been uncovered.

Loose granular materials like soil can be conveyed on a vibrating plate which uses a combined upward and rearward motion, that causes the material to move in a series of small hops as shown in Figure 5.

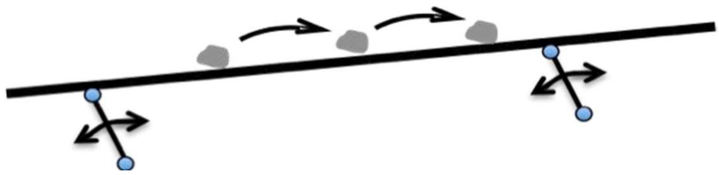


Figure 5: Action of vibratory conveyor

If the plate is replaced with a sieve then there will be a combined sieving and conveying action. Increasing the length of the sieve will increase the amount of sieving that occurs before the materials drops onto the soil surface.

4.5 Encouraging sieving

If arching is prevented by disturbing the soil mass, then simple sieving of the particles smaller than the spacing of the rods the will ensue. As a result clods and mines larger than the minimum will tend to pass along the sieve and not be shed to the side. The extent to which this occurs will depend on the speed of the conveying and the rate at which soil is fed onto the sieve. The latter will of course depend on the depth of working and the travel speed. It would obviously be desirable to prevent shedding and keep the soil stream in the sieve until it leaves the latter at the rear. This may be achieved by raising the rear of outer rods or even fitting low vertical 'walls' on the outside of the outer rods.

The value of vibration in sieving is enhanced by the well known principle that the vibration of particulate materials like soils in which there is a range of particle sizes will bring the larger particles upwards and allow the smaller particles to move downwards. The proposed vibratory motion here is therefore likely to be conducive to allowing the smaller particles to pass through the soil profile and the sieve and to leaving the larger particles, clods and mines on or near the surface when they leave the sieve at the rear. It is thought that the lifting of mines from say 150 mm would not require that the rear of the sieve be elevated by this amount.

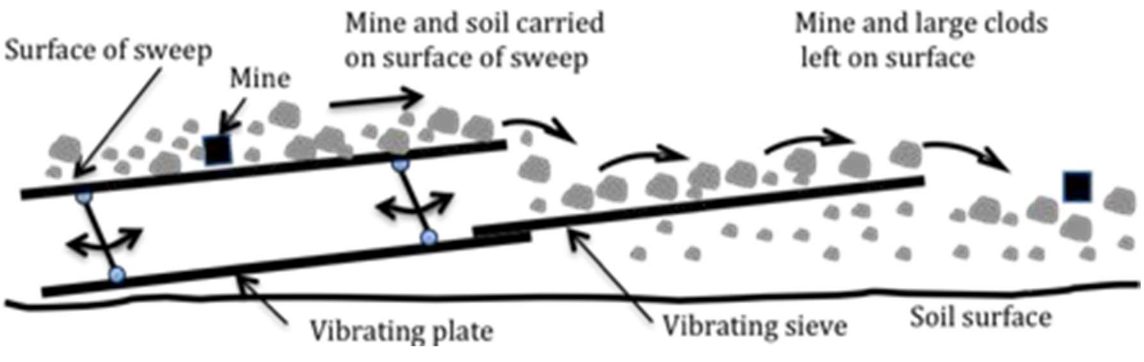


Figure 6: Schematic side elevation of the sieve and its mounting

5.0 Mounting the sieve

The soil disturbed by the sweep normally passes rearwards (relative to the sweep) and falls into the space behind the mounting bracket. In order to prevent this latter motion and allow the soil to pass onto the sieve the space behind the bracket was filled in with a steel sheet attached to the wings of the sweep. Bolting was used to allow ease of modification if required

The sieve, which was mounted on the under side of the sheet, projected to the rear of the sweep and was designed to fit behind its profile and so it would not be subject to any significant draft forces. For the sweep used in this trial the space available was approximately 30 mm in height and 300 mm wide. The height available was a very severe limitation to the design of the supports and the amplitude of the vibration which could be achieved.

Although the amplitude of the vibration is very small, the supports had to be sufficiently flexible to allow this amplitude to be achieved.

Two mounting systems were envisaged:

5.1 Elastic, non rotating supports

(a) Rubber mounts, vertical arrangement; angled arrangement — (b) Steel spring angled arrangement — (c) Pivoting links, angled arrangement

Figure 7: Alternative sieve mounts

Two alternative forms of support system were envisaged:

* rubber mounts (Figure 7(a) which it was thought would allow horizontal and vertical motion according to the angle at which they are driven.

The mounting pads were so called 'multi-cushions' (designed as vibration isolators) manufactured in Australia by Mackay Consolidated Industries. They were 25 mm dia. by 30 mm in height and composed of 40 Duro rubber bonded to steel end plates. The stiffness in compression and shear was 7 kg/mm and 1.3 kg/mm respectively.

The vertical arrangement using these multi-cushions was tried without any soil but this gave little vertical movement relative to the horizontal as the stiffness of the mount was greater in the vertical than the lateral direction. It also allowed considerable lateral and even rotational flexibility of the plate which did not promote the desired fore and aft motion.

The angled arrangement which would involve setting the mounts at a fixed mean angle to the vertical was not tried as this involved machining the mounting holes on the angle which time did not allow. It is likely that the mounting angle could be chosen to give appropriate vertical and horizontal components of motion.

* spring steel mounts (Figure 7(b)) could also be mounted at an fixed mean angle to the vertical (as for the rubber mounts) to give appropriate horizontal and vertical components of motion. The use of steel springs in this way would be similar to the angled rubber mounting

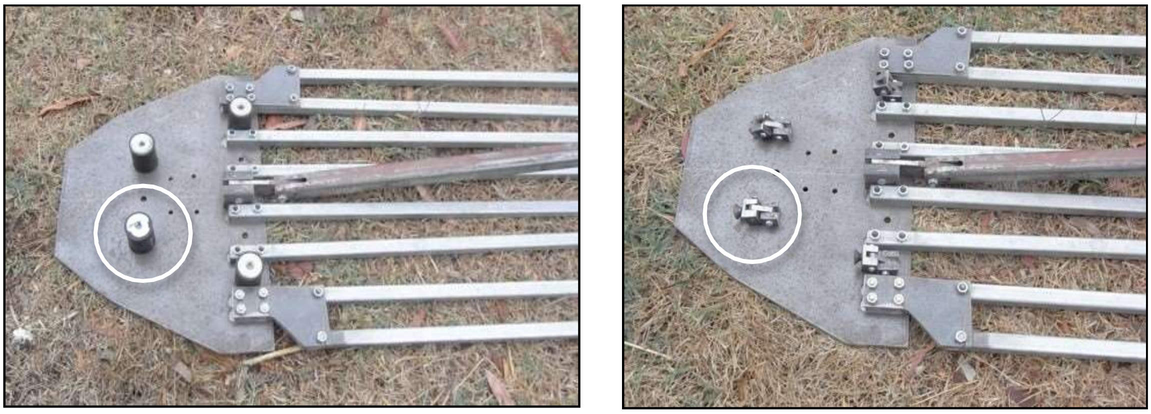
but it would have the desired effect of restricting the movement to the vertical longitudinal plane and largely prevent the lateral movement. Again this method was not tried.

5.2 Pivoting links (Figure 7(c))

A 'pendulum' arrangement in which the sieve with its associated mounting plate was supported by a series (four in this instance) of short pivoted links. This had the advantage that the motion was determined by the kinematic arrangement and that, in principle, the horizontal and vertical components of the motion could be varied by setting the mean position of pendulum links at an angle to the vertical. In the event the links were so short that the amount of variation possible was very limited.

The disadvantage of this arrangement is that the bearings would suffer rapid wear when operating in the space under the sweep where there is likely to be dust if not actual soil in contact with them.

However given the advantage of being able to set the motion of the sieve and the fact that this was a model was for trial purposes and was not intended to be a prototype the pendulum arrangement with un-hardened links and pivots was used.



(a) Rubber mounts (4) (b) Pendulum mounts (4)

Figure 8: Sieve mounting plate showing rubber and pendulum mounts

6.0 Trials

In order to allow ease of alteration and later adjustment the unit was assembled by bolting rather than being welded.

The mounting structure for the support of the motor and eccentric was therefore clamped to the tine and adjusted so these drive elements would be above the soil level when the tool was at working depth. This resulted in the connecting rod being some 24 degrees to the horizontal.

The rig was run out of the ground with the two mounting systems.

6.1 Rubber mounts

The support plate and attached rods were supported on the rubber mounts in a vertical position; see Figure 8(a). The limited deformation of the mounts did not allow their being preset to a significant extent and, in spite of the lifting effect of the angularity of the connecting rod, the resulting motion was nominally horizontal.

Superimposed on this appeared to be a rotational motion (as seen in the side elevation) due to the fact that the attachment point of the connecting rod was not at the centre of the rubber mounts (as seen in the plan view). This occurred for example when, as a result of the moment of the force from the connecting rod, the front mounts were compressed, the rear mounts extended.

A further complication was the fact that as a result of minor errors in the manufacture and assembly there was, in the plan view, a minor rotational oscillation of the mounting plate and sieve. It is understood that these additional vibrations would have assisted in the sieving process but they had the effect of at least masking the upward and rearward throw of the sieve.

The result was that while there was significant vibration the desired minimum requirement of some conveying had not been met. No trials were conducted in soil.

6.1 Pendulum links

Notwithstanding the limited space available and the likelihood of significant wear in the pivots this arrangement was used because it provided a defined and controllable motion and the ability to determine if the proposed upward / rearward motion of the sieve would result in suitable conveying and sieving action; see Figure 8 (b).

The connecting rod was adjusted for length so that at 'inside dead centre' the pendulum links were vertical and hence with a throw of the eccentric (double amplitude) of 8 mm at 'outside dead centre' the links were at 30 degrees to the vertical.

The conveying action of the soil particles and mass are dependent on friction on the steel rods and hence some roughening of the surface of the rods may assist in aspect of the conveying process.

(i) Trials with soil placed of sieve

Lumps of undisturbed soil (with grass roots) dug with a small in shovel were placed on the sieve and the rig run a maximum speed. The lumps tended to break up somewhat and small particles passed through the sieve; there were few fines and hence no observable arches. The lump and clods from any breakage passed (in some instances slowly) along the sieve and fell to the ground. It is thought that the continual movement of new soil onto the sieve would assist in this movement and during this testing the results with respect to both sieving and conveying were judged to be satisfactory. See video to be sent separately.

Figure 9: Soil manually placed on screen being conveyed and sieved

(ii) Trials in compacted, 'undisturbed' soil

The area which was relatively free of grass and surface trash had been cultivated a year earlier into a fine tilth and used for previous trials. However the surface layer with the gravel layer at some 100 to 150 mm below the surface (which is typical of the local profile) had, following winter rain, reformed into its 'undisturbed condition'. Any effect of the previous cultivation seemed to have disappeared.

As a result it was not possible to get the sweep to satisfactorily engage and draw itself into the profile. It did engage to some extent when started on a hole but would not stay engaged so the effectiveness of the sieve in continuous operation could not be evaluated. See video to be sent separately. Nor has it been possible to try the sweep (with or without the sieve) in different soil types and under different moisture conditions.

Figures 10 : *Tool working in hard undisturbed soil*

7. Conclusion

This paper reports on the preliminary trial of a small demining tool using an agricultural sweep. The design is based on the authors idea that the sweep would perform the required digging and sieving function particularly if the sieve was vibrated in the fore and aft direction; such vibration would provide a conveying function to encourage the rearwards flow of the soil.

The height of the space under the sweep was a severe limitation on the design. The work was also constrained to some extent by the resources available to the author, including the time available for the work and the type of soil available to test the machine.

The results suggest that, for the particular arrangement used and in the limited trials undertaken :

* the agricultural sweep would form a satisfactory basis for a demining tool if fitted with a vibrating sieve.

* the mounting system allowed and driving system provided the necessary vibratory motion

* the vibrating sieve with the associated conveying function performed satisfactorily in conveying and sieving the soil placed on it.

* some sideways shedding of the soil occurred but this is partly due to the fact that there is only one sieve in action during the trial.

The failure to get the sweep to engage and draw itself into the particular soil profile limited the evaluation of the sieve and the conclusions which can be drawn.

8. Future work

Again it should be emphasised that the unit was not intended as a prototype but as the basis for a preliminary investigation of the issues involved and as a guide for future work.

Further it is not suggested that the demining tool should necessarily be based on the particular sweep used in this work nor should the mounting or driving system used be seen as prototypical.

A similar design could be based on locally made commercial or especially manufactured tools.

Other alternatives suggest themselves which include combinations of:

(i) A more general 'constant force' vibration system (described above) acting in the fore and aft direction with or without the positive conveying function. This could be achieved using

* using a pair of contra - rotating out of balance rotors to give fore and aft vibration
* the rubber cushions as used above. If set at an angle to the vertical Figure 7 (b) a conveying function could be expected.

(ii) a specifically made sweep with a greater underneath space which would allow a larger pendulum system hence a greater lift and throw as well as a more rugged construction.

The trials with soil manually placed on the sieve (See *(i)* above), in which there was some conveying and sieving, would encourage the conclusion that a sieve, vibrated in a fore and aft direction, would be effective in separating mines. However it would be necessary to engage the sweep with the soil profile to the extent that it would lift the mines and allow them to pass onto the sieve.

This difficulty of getting this particular sweep to engage with the particular local soil in its dry, undisturbed condition illustrates the point made previously that there will need to be a range of types of tool to cope with the range of soil types and conditions. There may be the need to cultivate the area first with narrow tools so that the sweeps with sieve can engage the soil profile.

Data

Drive

Length of connecting rod = 450 mm

Angle of connecting rod = 24 degrees

Amplitude of vibration = ± 4 mm

Ratio connecting rod to radius of eccentric = 112

Angularity of connecting rod = 4/450 = ± 0.5 degree

Speed of eccentric = 200 rpm (approx)

Sieve

Angle of sieve = 7 degrees

Length of links = 14 mm

Maximum velocity of sieve = 3.14 x .004 x 200 = 2.4 m/s

Angle of maximum velocity to horizontal = 30 degrees

Length of rods = 400 mm

Width of sieve = 300 mm

Rod spacing = 42 mm

Rod size = 12 mm

Rubber cushions

Height = 30 mm

Diameter = 20 mm

Material = 40 Duro

Stiffness

Compression = 7 kg/mm

Shear = 1.3 kg/mm

9. Addendum (Oct 2019)

As noted earlier in the report the author is anxious to emphasise that, as it turned out, the design should not be seen as a 'prototype' but rather as an exploration of how the particular tool and its features performed, relative to the desired outcome. The shedding of the soil laterally, resulting in a trench, represented a major failure of the tool in that it did not allow the soil to pass over onto the sieve as envisaged. What might be concluded is that if the design allows, encourages or even forces the soil to pass onto the sieve then the latter is likely to be successful in bringing landmines to the surface

Subsequent consideration suggest the following:

(i) The use of a tool with a large sweep angle– 150 +/- 30 degrees. Large angles do not encourage grass and trash to be shedded to the side and so these might build up and have a bulldozing effect. If the large sweep angle is successful in allowing flow of the soil over the tool without significant shedding to the side, then the system may have to use other measures to remove the trash build up – lift the tool out of the soil, and / or reverse it to get rid of the trash. The best model for this type of tool and its operation is the so called 'blade plough' as developed in Canada for minimum tillage operations. A small version of this would be a good place to start.

(ii) Again if the soil flow is satisfactory then a more general (small amplitude) vibration (eg up-and-down) might be satisfactory and not necessarily the theoretically more logical fore-and-aft vibration as used in above.

(iii) If the more general, constant force vibration were to be used, then rubber mounts might be satisfactory and avoid the complication of the directional links as used above.

(iv) Significant weight might be necessary to ensure engagement with the soil.

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