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# STRING SIEVE: DESIGN CONCEPT AND PARAMETERS

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Abstract

This paper presents the design concept and the parameters of a new device for cleaning and-or sorting seeds and grain produced in a conventional farm. The discussed device is a string sieve where the groove between adjacent strings is minimal at the beginning of the screen and increases towards the end of the screen. The proposed sieve poses an alternative to a screen separator comprising a set of differently-sized mesh screens with longitudinal openings. In view of the average size of farm-produced seeds, the width of the separating groove should be set at 1 mm at the beginning of the screen and 11 mm at the end of the screen. In sieves not designed for grading large seeds or vetch seeds, the width of the separating groove can be set at 1 mm and 5 mm, respectively.

**Symbols:**
$d_s$ – string diameter,
$L$ – screen length,
$r_s$ – string spacing,
$s$ – width of groove at distance $x$ from the beginning of the screen,
$s_k$ – width of separating groove at the end of the screen,
$s_p$ – width of separating groove at the beginning of the screen,
$s_{s1}$ – maximum width of the groove between the top string and the bottom string in the first row,
$s_{s2}$ – maximum width of the groove between the top string and the bottom string in the second row,
$x$ – distance from the beginning of the screen,
$\beta_1$ – angle of inclination of bottom strings in the first row relative to top strings,
$\beta_2$ – angle of inclination of bottom strings in the second row relative to top strings,
$\gamma$ – opening angle between strings in bottom rows.

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## Introduction

A screen separator containing ten or more screens with different mesh sizes is one of the most popular devices for cleaning and sorting seeds. A screen separator comprises mesh screens with longitudinal and round openings whose dimensions are determined by the separator's grading efficiency and seed species. Mesh openings have regular shape and size across the entire screen. A single mesh screen can be applied to separate seeds into two fractions only: seeds that are captured by the mesh and seeds that pass through the mesh (GROCHOWICZ 1994). A seed mixture is separated by a mesh screen when the size of mesh openings falls within the distribution range of a given physical attribute of seeds, such as thickness or width. Several mesh screens are placed in the separator bucket to separate seeds into more than two fractions. Different screens are used to separate various seed species or differently sized seeds of the same species. Due to the fact that the above process is laborious and time-consuming, efforts were undertaken to develop a new solution for a cleaning machine that would not require mechanical modification to separate seeds of different species.

A string sieve for cleaning and sorting seeds has been developed by the author (KALINIEWICZ 2011). This paper analyzes the structure and geometric parameters of a string sieve, and it examines the proposed device's ability to clean and sort the principal seed species produced by a conventional farm.

## Structure of a string sieve

A string sieve was designed as an alternative for a conventional screen separator containing a set of exchangeable mesh screens with longitudinal openings. The proposed sieve will be used for sorting and cleaning seeds produced by a conventional farm. The designed sorting device with a single separating element is easy to operate and control.

The operating element in the proposed sorting machine is a surface with grooves whose width is minimal at the beginning of the screen and increases towards the end of the screen. The screen is set at a certain angle, and the seed mixture which is fed at the beginning of the screen slides down the screen automatically or when it is set into reciprocating motion. The seed mixture travels across the screen, and increasingly thicker fractions are separated as seeds move away from the beginning of the screen (feeding point). The operating element does not contain flat surfaces which would allow the seeds to bypass the respective separation areas.

A structural diagram of a string sieve (KALINIEWICZ 2011) is presented in Figure 1. Strings are stretched between two horizontal bars. At the beginning of the screen, strings are separated by equal distances in a single row (with

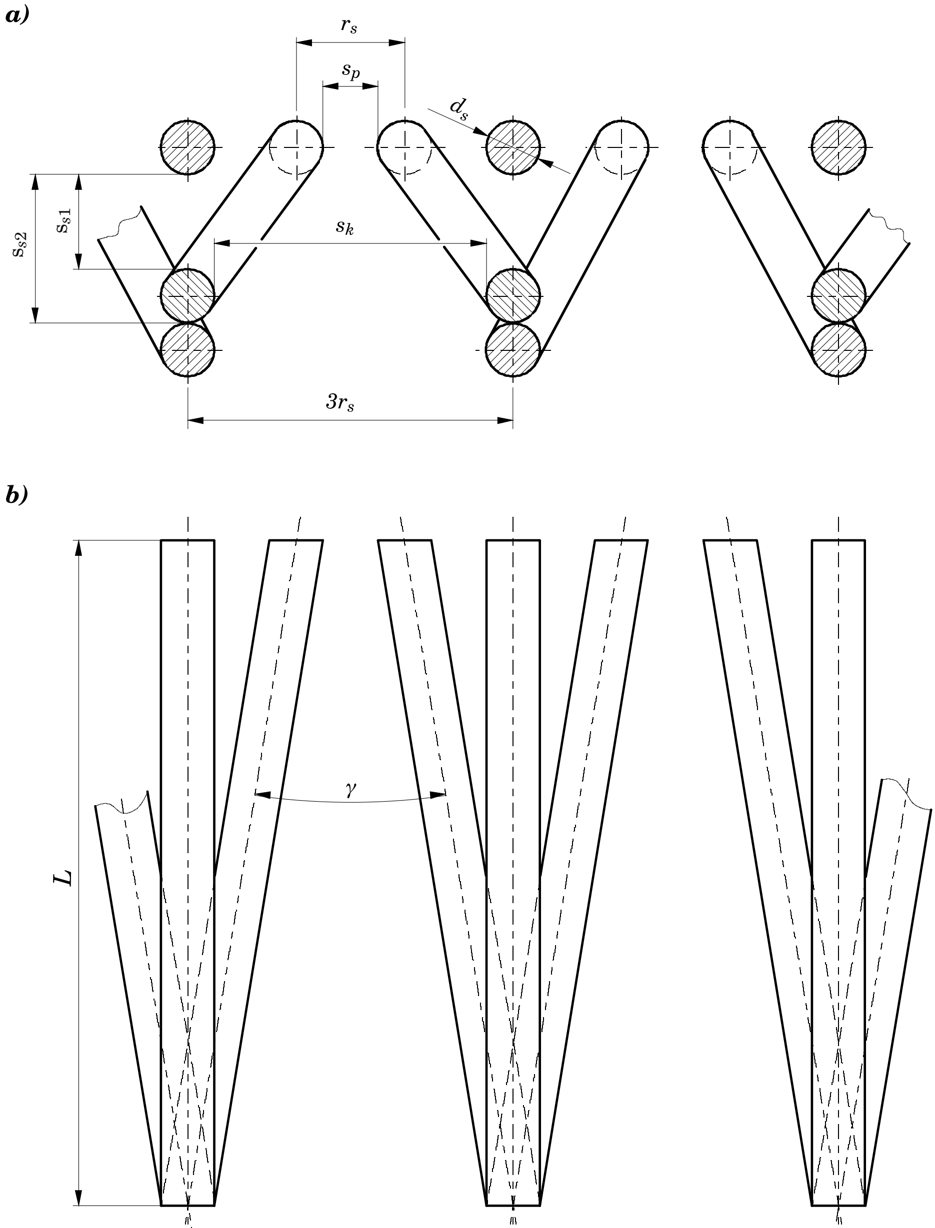


Fig. 1. String arrangement in a string sieve: *a* – rear view, *b* – top view

string spacing $r_s$), and the width of openings $s_p$ between strings has to be smaller than the thickness of the finest seeds of the principal species. At the end of the screen, strings are stretched in three rows, and every set of three strings is set in a vertical plane (one string under another). The width of the opening $s_k$ between strings should be larger than the thickness of the largest seeds of the principal species. This arrangement creates a separating groove along the screen, and its size changes gradually with distance from the beginning of the screen in the range of $s_p$ to $s_k$. Lateral grooves are formed between top and bottom row strings, and their width changes along the screen in the range of $s_p$ to $s_{s1}$ or $s_{s2}$. Seeds are not sorted by lateral grooves whose width is identical to that of the separating groove only at the beginning of the screen and continues to decrease towards the end of the screen. Seeds which initially fall into lateral grooves due to the designed string arrangement will move perpendicularly to the angle of inclination of lateral grooves, and they will ultimately fall into the main separating grooves. Seeds are sorted into various size fractions by changing the position of collecting buckets under the screen.

A string sieve can be made of wires or rods with circular, square, triangular or hexagonal cross-section. Strings with non-circular cross-section have to be turned around their axis to ensure that their flat surface is not aligned perpendicularly to screen surface. Strings can be made of various materials with the required strength, and they may be additionally coated with rubber or plastic. A sieve comprising strings with a circular cross-section will be analyzed in this paper.

The width of the separating groove at the beginning and end of the screen can be determined with the use of the following formulas:

$$s_p = r_s - d_s \tag{1}$$

$$s_k = 3r_s - d_s \tag{2}$$

and the resulting values are transformed to produce:

$$d_s = \frac{s_k - 3s_p}{2} \tag{3}$$

$$r_s = \frac{s_k - s_p}{2} \tag{4}$$

Thus, the specific widths of the separating groove at the beginning and end of the screen correspond to a single arrangement of string spacing and string diameter. The width of the separating groove changes with distance from the beginning of the screen. In line with the principle of similar triangles (Fig. 2):

$$\frac{(s - s_p)}{x} = \frac{(s_k - s_p)}{L} \tag{5}$$

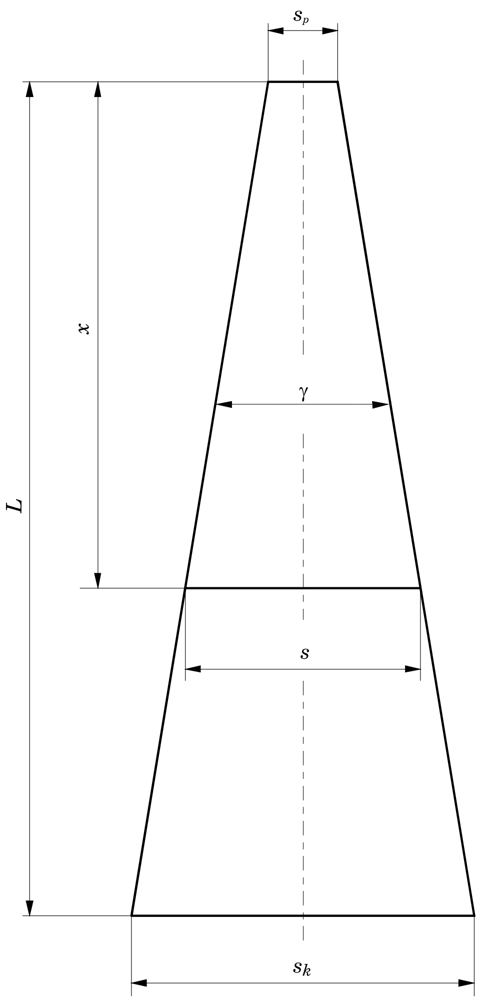


Fig. 2. Groove parameters in a string sieve

When formula (5) is transformed accordingly, the width of groove $s$ at a given point in the screen is described by the following dependency:

$$s = \frac{(s_k - s_p) \cdot x}{L} + s_p \tag{6}$$

At this point, seeds whose thickness matches the width of the groove should be placed in the collection bucket, while larger seeds should travel further across the surface of the sieve.

Based on general trigonometric equations, the opening angle between strings $\gamma$ can be determined from the following formula:

$$\gamma = \text{arc tg}\,\frac{s_k - s_p}{L} \tag{7}$$

and the angle of inclination between top and bottom strings:

$$\beta_1 = \text{arc tg}\,\frac{s_{s1} + d_s}{L} \tag{8}$$

$$\beta_2 = \text{arc tg}\,\frac{s_{s2} + d_s}{L} \tag{9}$$

In principle, lateral grooves between top and bottom strings ($s_{s1}$ and $s_{s2}$ at the end of the screen) (Fig. 1) are not designed for seed grading. To prevent seeds from leaving the screen via lateral grooves, the width of lateral grooves should not exceed the width of the main separating groove $s_k$. Since bottom row strings at the end of the screen form two levels, the above requirement applies mainly to the width of groove $s_{s2}$ because in accordance with the below formula, the width of groove $s_{s1}$ is always smaller:

$$s_{s2} = s_{s1} + d_s \tag{10}$$

Based on the assumption that grooves have equal width, i.e. $ss_2 = s_k$, and in view of equation (3), equations (8) and (9) take on the following form:

$$\beta_1 = \text{arc tg}\,\frac{s_k}{L} \tag{11}$$

$$\beta_2 = \text{arc tg}\,\frac{3(s_k - s_p)}{2L} \tag{12}$$

The proposed arrangement of strings, which results in the above angles between strings, increases grading efficiency because seeds move across the surface of the sieve faster than implied by its angle of inclination.

## Geometric attributes of seeds

Seed cleaning and grading machines have to be designed in view of the physical parameters of processed material (GROCHOWICZ 1994). Physical attributes are needed to design successive stages of the separation process and produce seed material of required quality (MAJEWSKA et al. 2000). A knowledge of the processed material's physical parameters is also required to model production, acquisition, transportation, cleaning, sorting, drying and storage processes (ALTUNTAS, DEMIRTOLA 2007, ÇALIŞIR et al. 2005, DAVIES, EL-OKENE 2009, GROCHOWICZ 1994, KALKAN, KARA 2011, KUSIŃSKA 2004, RYBIŃSKI, SZOT 2009).

Seed dimensions are determined by various factors, mostly soil and climate conditions, agricultural practices and the varietal characteristics of seeds (*Szczegółowa....* 2003a, 2003b). Variations in seed size may also result from seed position on the maternal plant (BRZEZIŃSKI, KLOCKIEWICZ-KAMIŃSKA 1997, FORNAL, KUBIAK 1995, GEODECKI, GRUNDAS 2003), seed moisture content (ALTUNTAS, DEMIRTOLA 2007, ÇALIŞIR et al. 2005, DAWIES, EL-OKENE 2009, GHARIBZAHEDI et al. 2011, IZLI et al. 2009, KALKAN, KARA 2011, KUSIŃSKA 2004, KUSIŃSKA et al. 2010, SOLOGUBIK et al. 2013, YALÇIN et al. 2007) and time of storage (KUSIŃSKA 2004).

A knowledge of the basic geometric parameters of separated seeds, in particular seed thickness, is required for the proposed device to pose an effective alternative to a screen separator containing a set of mesh screens with longitudinal openings.

The dimensions of various seed species with adequate storage moisture levels, without an indication of seed cultivar or cultivation method, are presented in Table 1. The thickness of fine seeds (rapeseed, mustard) varies in the range of 1.1 to 2.5 mm. The thickness of principal cereal seeds ranges from 1.2 mm (oats and rye) to 4.7 mm (barley). Similar values are reported for buckwheat seeds, whereas vetch seeds may be somewhat larger (up to 6.1 mm). The thickness of larger grain seeds varies in the range of 2.9 mm (lupine) to 10.1 mm (pea). As shown by Table 1 data, seeds produced by a typical agricultural farm can be classified into the following size ranges:
– thickness – 1.1 ÷ 10.1 mm,
– width – 1.1 ÷ 10.8 mm,
– length – 1.4 ÷ 18.6 mm.

Table 1

Geometric parameters of seeds

| Seed species | Seed group | Dimensions | | | References |
|---|---|---|---|---|---|
| | | thickness [mm] | width [mm] | length [mm] | |
| Mustard | I | 1.1÷2.4 | 1.1÷2.7 | 1.4÷3.0 | 3, 4 |
| Rapeseed | | 1.2÷2.5 | 1.6÷2.8 | 1.7÷2.8 | 1, 4, 24, 25, 26 |
| Barley | II | 1.4÷4.7 | 2.0÷5.0 | 7.0÷14.6 | 6, 11, 12, 13 |
| Oats | | 1.2÷3.6 | 1.4÷4.0 | 8.0÷18.6 | 6, 11, 18 |
| Wheat | | 1.4÷3.9 | 1.6÷4.5 | 4.3÷10.2 | 6, 19, 20, 21, 22, 23 |
| Triticale | | 1.7÷4.1 | 1.9÷4.3 | 5.3÷10.4 | 1, 21 |
| Rye | | 1.2÷3.5 | 1.5÷3.6 | 5.0÷10.5 | 21, 27, 28 |
| Buckwheat | | 2.0÷4.2 | 3.0÷5.2 | 4.4÷8.0 | 6, 9, 10 |
| Vetch | III | 2.0÷6.1 | 3.2÷6.3 | 3.2÷7.5 | 1, 6, 7 |
| Faba bean | IV | 5.5÷9.9 | 5.8÷10.8 | 7.1÷14.2 | 1, 2 |
| Pea | | 3.5÷10.1 | 3.7÷10.2 | 4.0÷10.5 | 5, 6, 7, 8 |
| Lupine | | 2.9÷8.5 | 3.1÷8.5 | 3.9÷13.6 | 6, 14, 15, 16, 17 |

1 – Markowski (2007), 2 – Mieszkalski (1991), 3 – Jadwisieńczak, Kaliniewicz (2011), 4 – Choszcz, Wierzbicki (1994), 5 – Altuntas, Demirtola (2007), 6 – Grochowicz (1994), 7 – Rybiński et al. (2009), 8 – Yalçin et al. (2007), 9 – Kaliniewicz, Rawa (2001), 10 – Kram et al. (2007), 11 – Hebda, Micek (2007), 12 – Sadowska, Żabiński (2009), 13 – Sologubik et al. (2013), 14 – Kamińska, Andrejko (2006), 15 – Lema et al. (2005), 16 – Mańkowski (2004), 17 – Sadowska, Żabiński (2011), 18 – Kusińska (2004), 19 – Choszcz et al. (2010), 20 – Geodecki, Grundas (2003), 21 – Hebda, Micek (2005), 22 – Kalkan, Kara (2011), 23 – Segit et al. (2003), 24 – Çalişir et al. (2005), 25 – Izli et al. (2009), 26 – Rawa et al. (1990), 27 – Kusińska et al. (2010), 28 – Zdybel et al. (2009).

## Parameters of a string sieve

In accordance with Equations (3) and (4), the specific widths of the separating groove at the beginning and end of the screen correspond to a single arrangement of string spacing and string diameter. The parameters of a sieve for grading various seed species are presented in Table 2. According to the methodological assumptions, the surface of the string sieve should be used in the sorting process to the highest possible degree, i.e. the width of a given groove at the beginning of the screen should be somewhat smaller than the thickness of the finest seeds of the principle species, and the width of the groove at the end of the screen – somewhat larger than the thickness of the largest seeds of the principal species. The width of the groove for separating fine seeds (group I) should be 1 mm at the beginning of the screen and 3 mm at the end of the screen. In line with formula (3), a string sieve cannot be designed for the above parameters because string thickness $d_s$ = 0 mm. If string thickness $d_s$ = 0.5 mm and if the width of the groove at the beginning of the screen $s_p$ = 1 mm, then based on formula (3), the width of the groove at the end of the screen $s_k$ = 4 mm. In this situation, the screen will not be fully utilized

Table 2

Parameters of a string sieve for grading groups of seeds of different thickness

| Parameter | Seed group | | | | | | |
|---|---|---|---|---|---|---|---|
| | I | II | I+II | III | I+II+III | IV | I+II+III+IV |
| $s_p$ [mm] | 1.0 | 1.0 | 1.0 | 1.5 | 1.0 | 2.5 | 1.0 |
| $s_k$ [mm] | (3.0) 4.0 | 5.0 | 5.0 | 6.5 | 6.5 | 11.0 | 11.0 |
| $d_s$ [mm] | (0) 0.5 | 1.0 | 1.0 | 1.0 | 1.75 | 1.75 | 4.0 |
| $r_s$ [mm] | (1.0) 1.5 | 2.0 | 2.0 | 2.5 | 2.75 | 4.25 | 5.0 |

I – fine seeds (rapeseed, mustard),
II – principal cereals (wheat, rye, barley, oats and triticale) and buckwheat,
III – vetch,
IV – large seeds (pea, lupine, faba bean).

because all seeds will fall through the grooves at approximately 2/3 of its length.

For cereal and buckwheat seeds (group II), the width of the groove at the beginning and end of the screen should be 1 mm and 5 mm, respectively, with string diameter of 1 mm and string spacing of 2 mm. A sieve with string diameter of 1 mm and string spacing of 2.5 mm can be applied to sort vetch seeds (group III) because the resulting width of the grooves at the beginning and end of the screen will reach 1.5 mm and 6.5 mm, respectively. A sieve for grading seeds from groups I, II and III should comprise strings with the diameter of 1.75 mm, separated by a distance of 2.75 mm. The resulting width of the groove would reach 1 mm at the beginning of the screen and 6.5 mm at the end of the screen. A sieve for sorting larger seeds (group IV) should be designed with groove width of 2.5 mm and 11 mm at the beginning and end of the screen, respectively. This solution requires strings with the diameter of 1.75 mm and string spacing of 4.25 mm.

In a sieve capable of separating all of the seed species given in Table 1 (groups I, II, III and IV), the width of the separating groove should be set at 1 mm at the beginning of the screen and at 11 mm at the end of the screen. In sieves designed for grading principal cereal seeds, buckwheat seeds and fine seeds (groups I and II), the respective parameters should be 1 mm and 5 mm.

The proposed string sieve will sort seeds into minimum three size fractions, and the sorting surface for each fraction will have the minimum length of 20 cm. This means that total sieve length will be minimum $L$ = 60 cm. If the separating groove at the end of the screen has the width $sk$ = 11 mm, the opening angle between strings will reach $\gamma = 0.95°$. Sieves which are longer and/or have narrower grooves at the end of the screen will have a smaller opening angle between strings.

In a sieve with minimum length ($L$ = 60 cm) and the widest groove at the end of the screen ($s_k$ = 11 mm), the angles of inclination of bottom strings relative to top strings will reach $\beta_1$ = 1.05° and $\beta_2$ = 1.43°, respectively. Sieves which are longer and/or have narrower grooves at the end of the screen will have smaller angles of inclination.

## Conclusions

The proposed string sieve poses an alternative for a screen separator comprising a set of mesh screens with longitudinal openings. The width of separating grooves changes gradually towards the end of the screen. In the designed sieve, seeds are separated into different fractions by changing the position of collection buckets under the string sieve. In devices capable of separating the majority of seeds produced by a conventional farm, the width of the separating groove should be set at 1 mm at the beginning of the screen and at 11 mm at the end of the screen. In sieves which are not designed for grading large seeds (faba bean, pea, lupine) or vetch seeds, the respective parameters should be 1 mm and 5 mm.

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