

Development of belt sorters smoothly adjustable belt drums

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Abstract. Belt sorters are used to sort different type of objects according by their size. Making belt sorter easily and quickly adjustable in desired range has positive influence on it's functionality and productivity. One solution for that is to use one or more adjustable belt drums. This option allows to change the distance between belts evenly and through this change the mesh size so to speak. Greater benefits will be obtained if belt drum is smoothly adjustable. The aim of this research paper is to compare technical peculiarities of two patented technical solutions for smoothly adjustable drum and identify if the newer has benefits compared with the older one. In this study comparative tests are performed using real prototypes. Both prototypes have key structure that determine the range of their adjustability. Prototype with older technical solution contains CNC milled key structure and prototype with improved solution contains 3D printed key structure. Prototype's mechanical parameters like belt pulleys backlash relative to the fixing point, backlash between two neighboring belt pulleys and required torque to regulate slot width between belt pulleys are studied. Also, it is considered how both technical solutions influence the sorting quality. During this study different measuring instruments are used included laser scanner. Obtained results are used to develop better and more reliable technical solution for belt sorters that can be used in berry processing lines.

Key words: agricultural engineering, post-harvest treatment, berry sorter, blueberry, product development.

INTRODUCTION

Belt sorter with adjustable fractioning slot has wider utilisation range than belt sorter without that function. For example, when sorting berries then it is possible to use adjustable sorter for different berry varieties or to adjust berry fraction size by customer needs. Thus, it will increase utilisation possibilities of berries' post-harvest processing lines with belt sorters like Lakewood Process Machinery (2014) produces (Olt, 2015; Soots & Olt, 2016). Belt sorter sorting area is formed by belts that are placed on drums. Drums should have rabbets on their sides to fixate belts in the right position thus determining fractioning slot width between belts. The idea of making belt sorter adjustable is to distribute belt pulleys' rabbets evenly along the axis of drum. This can be done using one or more smoothly adjustable drums. For the belt sorter to be applicable in practice, the adjusting process should be fast, easy and uniform.

According to our previous research (Soots et al., 2014) technical solution, that is described in patent EE05642 B1 (hereinafter referred to as 1st generation), has problems with belt pulleys' backlash relative to the fixing point in a work situation. It causes changes in fractioning slot width between belts and that affects uniformity of sorted

fractions (Soots et al., 2014). 1st generation has a technical flaw which may cause this problem. More precisely, the key structure in 1st generation is steering shaft (patent EE05642 B1, 2013). Steering shaft moves and fixes belt pulleys on pipe-shaped casing. Steering shaft has right-hand and left-hand guiding grooves with variable step. Every belt pulley is connected to the steering shaft through the longitudinal opening in pipe-shaped casing with a single bolt in such a way that the tip of the bolt reaches inside the guiding groove of the steering shaft (patent EE05642 B1, 2013; Soots et al., 2014). The problem of the backlash comes from the fact that every belt pulley is connected to the steering shaft by only one bolt. This problem could be solved by adding extra fixing points to each pulley. Unfortunately, it cannot be done in the case of 1st generation because guiding grooves will overlap each other and that may cause malfunctions during adjustment.

To solve this problem, new and improved technical solution was developed. This 2nd generation technical construction is described in patent application P201400049 (in press). If the key structure in the 1st generation construction is a single-piece steering shaft with guiding grooves to move and fix belt pulleys, then the key structure in the 2nd generation construction contains whole set of cores and sleeves (see Fig. 1) that allow to adjust distance between belt pulleys evenly.

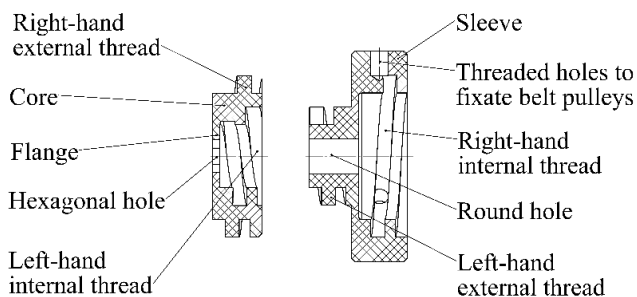


Figure 1. 2nd generation core and sleeve cross-section view.

Beside the need to improve how belt pulleys move and fix, the pipe-shaped casing production technology needs improvement too. The pipe-shaped casing with one longitudinal opening of the 1st generation construction is made of welded cold drawn cylinder steel tube. Reason for using this kind of tube is that the tube's inner and outer surface must be smooth and dimensionally accurate. When the longitudinal opening was milled in the tube, the diameter of the tube increased in the middle of tube probably due to internal stress. This causes a need to remove extra material with turning to ensure accurate and even outer diameter of the tube.

The aim of this research is to compare technical differences of the two patented technical solutions for smoothly adjustable drum and identify if the newer construction has any benefits compared to the older one. To accomplish this, following steps were taken and measurements done:

1. Prototyping 2nd generation core and sleeve.
2. Performing stress relieving annealing for pipe-shaped casing before milling longitudinal openings and determining outer diameter change.
3. Measuring backlash between two neighboring belt pulleys.

4. Measuring belt pulleys backlash relative to the fixing point when belt pulleys are fixed at one point.
5. Measuring the torque that is required to regulate slot width between belt pulleys.

MATERIALS AND METHODS

For tests, prototypes of both generations are required. 1st generation remained from our previous research (Soots et al., 2014), but 2nd generation prototype was specifically manufactured for the purposes of this research.

Prototyping core and sleeve for 2nd generation

2nd generation core and sleeve given in Fig. 1 were manufactured by 3D printing. 3D printing is widely used for this kind of rapid prototyping (Wu et al., 2015). 3D printing has many different technologies but in this case fused deposit modelling (FDM) 3D printing was used. This technology was chosen due to its ability to manufacture complex parts quickly and easily with modest costs. The idea of FDM technology is to create details layer by layer with thermoplastic filament (Palermo, 2013; Wu et al., 2015; Stratasys Ltd., 2016). In this research Stratasys uPrint SE Plus was used and the printing layer height was 0.254 mm (Stratasys Ltd., 2016). Reason why this 3D printer was chosen is that it allows to print soluble support material in addition to the basic material. 3D printing doesn't allow to print in the air and protruding parts of the details need to be supported from below. Many FDM technology 3D printers print the parts and required supports using the same material and after printing, supports are removed mechanically thus, the detail surface quality may decrease. With Stratasys uPrint SE Plus 3D printer the supports are printed with soluble material that are later removed in a special cleaning machine. In this research Stratasys WaveWash support cleaning system was used to remove supports from core and sleeve. To ensure core rotational movement in the sleeves, clearance of 0.25 mm between the printed parts was chosen for 3D printing (Peets, 2016).

Pipe-shaped casing manufacturing

2nd generation pipe-shaped casing is made of welded cold drawn cylinder tube that is made of steel E355 (Novero S.P.A., 2016). Inner diameter of the used tube is 70 mm and outer diameter 80 mm, according to manufacturer's certificate (Novero S.P.A., 2016). While 1st generation pipe-shaped casing has just one longitudinal opening, 2nd generation casing has three openings in order to add the extra belt pulleys' fixing points to the regulating element. Before milling the longitudinal openings in pipe-shaped casing, the stress relieving annealing was performed. According to material certificate, this must be done at temperature 580–630 °C and holding time of 1–2 min per mm of plate thickness, but holding time must be at least 30 min (Fischer et al, 2010; ThyssenKrupp, 2016). The thermal treatment was done at the local aluminium casting workshop at 450 °C with duration of 4.5 hours. After the thermal treatment and milling, the pipe-shaped casing's outer diameter was measured with Nikon measuring arm MCAX20 combined with laser scanner MMDx50. According to Nikon Metrology NV, 2016, accuracy of this laser scanning system is 50 µm. Obtained results were processed with Nikon Focus software. Outer diameter was measured in five places on the tube.

First measurement was taken 3 mm from the beginning of the tube, following four measurements with 130 mm increments.

In addition to thermal treatment of the pipe-shaped casing, changes in the construction of longitudinal openings were also made. Compared to 1st generation, the 2nd generation pipe-shaped casing has two small bridges in between each longitudinal opening as it is shown in Fig. 2.

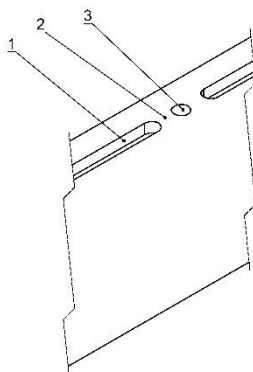


Figure 2. Bridges in between longitudinal openings (1 – longitudinal openings; 2 – bridges; 3 – opening for middle belt pulley fixing element).

This improvement in construction of the longitudinal opening should guarantee that the outer diameter remains constant after milling longitudinal openings even if the thermal treatment has not fully relieved the inner stress of the casing.

Backlash between two neighboring belt pulleys

Backlash between two neighboring belt pulleys was measured with Mitutoyo Absolut AOS Digimatic Caliper (code no 500–161–30) with accuracy ± 0.02 mm (Mitutoyo, 2016). Measurements were made at minimum, medium and maximum slot width (0, 6 and 10 mm, respectively) with both generations. 1st generation prototype has 23 belt pulleys and 2nd generation prototype has 17 belt pulleys.

Belt pulleys' backlash relative to the fixing point

Belt pulleys' backlash relative to the fixing point when belt pulleys are fixed at one point was measured. This is the biggest problem with 1st generation construction (Soots et al., 2014). Measurements were made using Mitutoyo Absolut AOS Digimatic Caliper (code no 500–161–30) with accuracy ± 0.02 mm (Mitutoyo, 2016). Measurements were taken in medium slot width, where slot width between belt pulleys is 6 mm. In case of 1st generation construction, each belt pulley has one fixing point to the steering shaft and measurements were taken at the opposite side of fixing points. In case of 2nd generation construction, each belt pulley has three fixing points to the sleeve and measurements were taken at the opposite side of each fixing point.

Required torque to regulate slot width between belt pulleys

Required torque to regulate the slot width between belt pulleys must be determined in such a way that torque, rotational speed of the regulating lever, and angle of rotation can be measured continuously at the same time. Tests were carried out with tensile testing system Instron 5969, 1 kN load cell was used. Picture of the test setup to measure required torque to regulate slot width between belt pulleys is shown in Fig. 3.

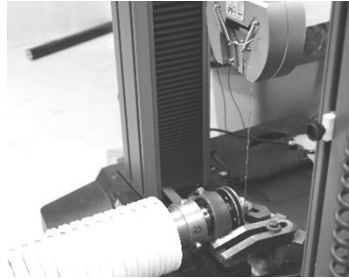


Figure 3. Picture of the test setup to measure required torque to regulate slot width between belt pulleys.

As it is shown in Fig. 3, smoothly adjustable drum is fixed to the base of tensile testing system. Regulating lever of drum is connected via grip to steel hawser. Diameter of the regulating lever is 29.90 mm for 1st generation and 30.09 mm for 2nd generation construction. For tests, tensile speeds of 30 mm min⁻¹ and 130 mm min⁻¹ were used. When converted to the rotational speeds of the handle, 1st generation handle rotational speeds are 0.32 min⁻¹ and 1.384 min⁻¹ and 2nd generation handle rotational speeds are 0.318 min⁻¹ and 1.376 min⁻¹. Handle rotation scope for 1st generation is 340 deg and for 2nd generation is 215 deg. All tests were performed without belts and without any force on belt pulleys.

RESULTS AND DISCUSSION

Prototyping core and sleeve for 2nd generation

2nd generation 3D printed core and sleeve are shown in Fig. 4. In the figure also support material (white) can be seen.



Figure 4. 2nd generation 3D printed core and sleeve.

Results show that used 3D printing technology is suitable for function testing. With used FDM technology, parts are printed layer by layer and threads' surfaces are not smooth. They remind little steps as can be seen in Fig. 4. The smaller is thickness of the printed layer - the smaller are the steps. The used 3D printer allows to use minimal layer thickness of 0.254 mm, so the steps are 0.254 mm high. This affects parts surface roughness and thereby core movement inside the sleeves.

Chosen clearance between the printed parts was sufficient to obtain movement between them and only minor mechanical polishing and oil lubrication was required.

Pipe-shaped casing manufacturing

The results of outer diameter measurements of the pipe-shaped casing are shown in Fig. 5.

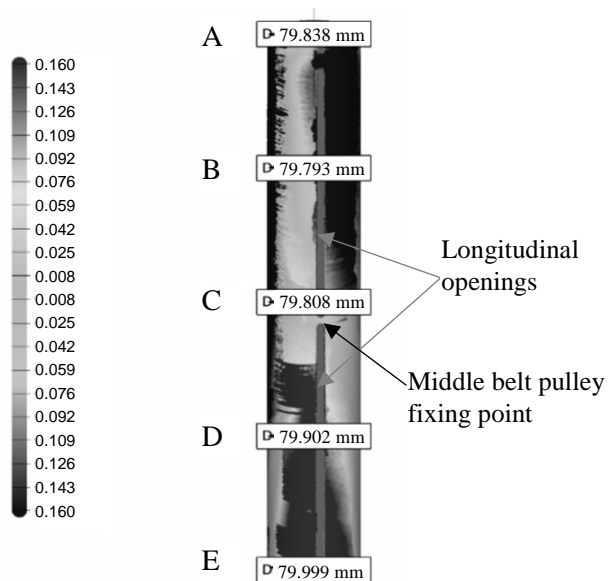


Figure 5. Determination of outer diameter of the pipe-shaped casing.

According to the pipe manufacturer's certificate nominal outer diameter of the pipe is 80 mm, tolerances are not given. All the obtained results stayed below that value and did not show any increase of outer diameter in the middle of longitudinal openings (Fig. 5 measurements in points B and D) compared to the middle and ends of pipe-shaped casing.

Backlash between two neighboring belt pulleys

Results of the tests where backlash between two neighboring belt pulleys was measured are shown in Figs 6 and 7.

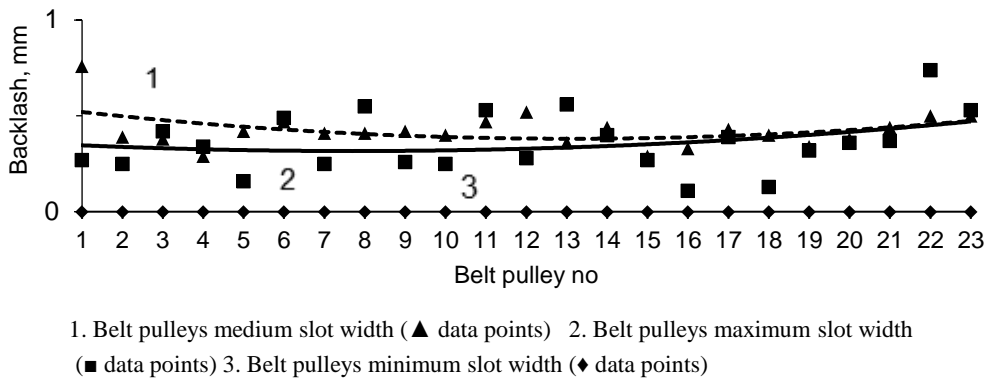


Figure 6. 1st generation backlash between two neighboring belt pulleys.

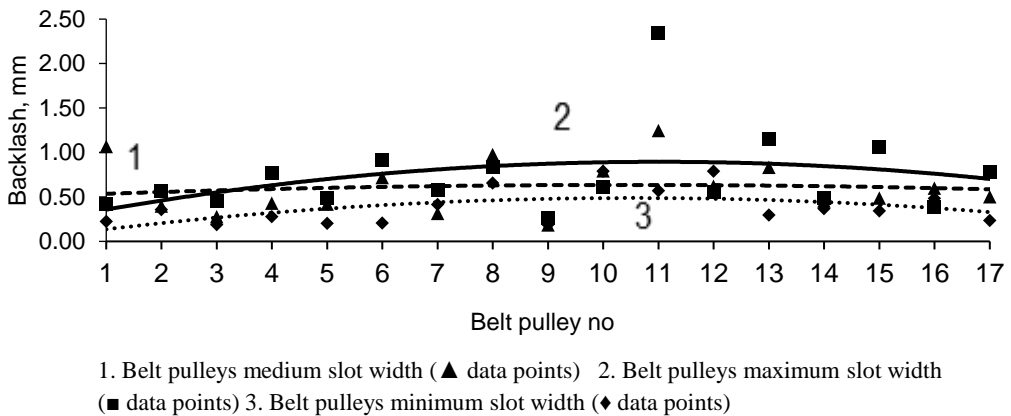


Figure 7. 2nd generation backlash between two neighboring belt pulleys.

Results of tests where backlash between two neighboring belt pulleys were measured shows that:

1. 1st generation backlash between two neighboring belt pulleys is smaller than that of 2nd generation.
 - a. at minimum slot width between belt pulleys, 1st generation average backlash between two neighboring belt pulleys is 0 mm. In case of 2nd generation, average backlash is 0.40 mm at the same conditions.
 - b. at average slot width between belt pulleys, 1st generation average backlash between two neighboring belt pulleys is 0.42 mm. In case of 2nd generation, average backlash is 0.61 mm at the same conditions.
 - c. at maximum slot width between belt pulleys, 1st generation average backlash between two neighboring belt pulleys is 0.36 mm. In case of 2nd generation, average backlash is 0.74 mm at the same conditions.
2. 2nd generation the outermost belt pulley's backlash relative to the middle one depends on the backlashes of other belt pulleys that are between them. This is due to the

constructional peculiarities of II generation. Particularly, that outermost sleeve is connected to the middle sleeve through all cores and sleeves between them and the clearances of all the threads accumulate.

3. 1st generation outermost belt pulley backlash relative to the middle one doesn't depend on backlash of other belt pulleys because every thread is independent on a single solid steering shaft.

4. In case of both generations, average backlashes between two neighboring belt pulleys depend on the slot width between belt pulleys.

Belt pulleys backlash relative to the fixing point

Test results for belt pulleys backlash relative to the fixing point are given in the Figs 8 and 9.

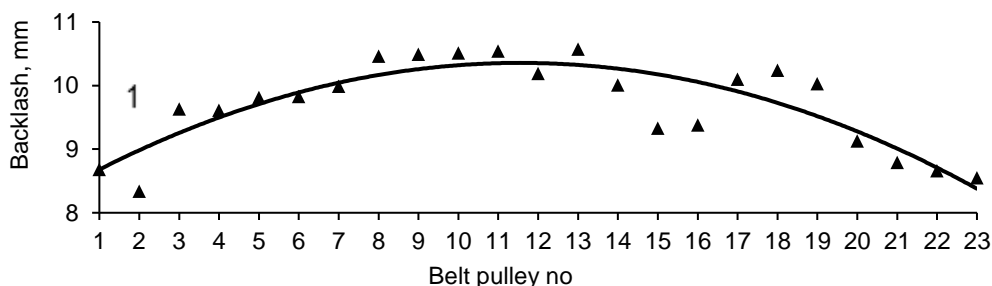


Figure 8. 1st generation belt pulleys backlash with medium slot width, measured at the opposite side of belt pulley fixing point.

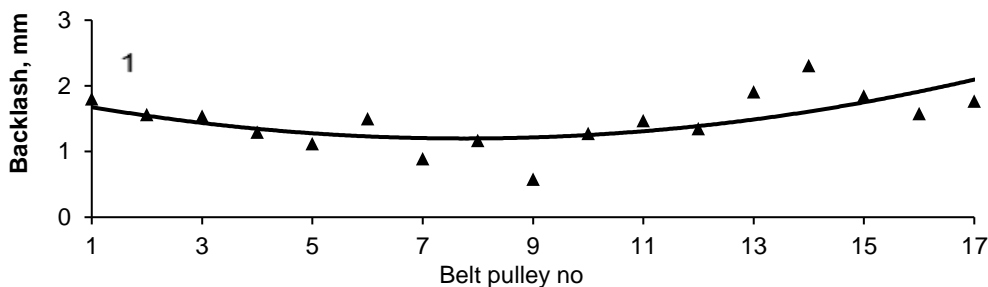


Figure 9. 2nd generation belt pulleys backlash with medium slot width, measured at three opposite sides of belt pulleys fixing points.

Obtained test results about belt pulleys backlash relative to the fixing point show that:

1. 1st generation belt pulleys' backlash (maximum 10.57 mm) is greater than 2nd generation (maximum 2.31 mm).
2. 1st generation belt pulleys' backlash decreases away from the middle of pipe-shaped casing where the middle belt pulley is fixed.
3. 2nd generation belt pulleys' backlash increases away from the middle of pipe-shaped casing where the middle belt pulley is fixed.

Required torque to regulate slot width between belt pulleys

Test results for required torque to regulate slot width between belt pulleys are shown in Figs 10–13. Handle position of 0 deg in Figs 10 and 12 indicates minimum slot width between belt pulleys. In Figs 11 and 13 the 0 deg indicates maximum slot width between belt pulleys. While Figs 10–13 show the shape of curves, Fig. 14 shows the summarized results from tests.

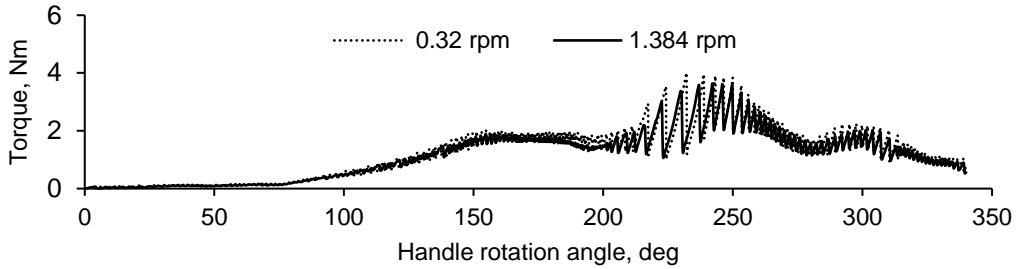


Figure 10. Required torque to increase the slot width between belt pulleys for 1st generation with two regulating speeds.

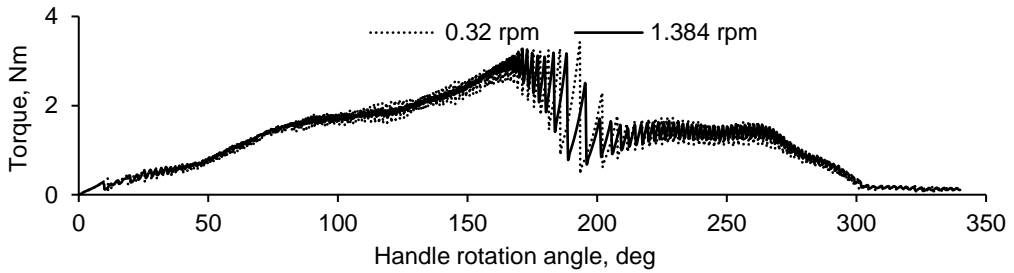


Figure 11. Required torque to decrease the slot width between belt pulleys for 1st generation with two regulating speeds.

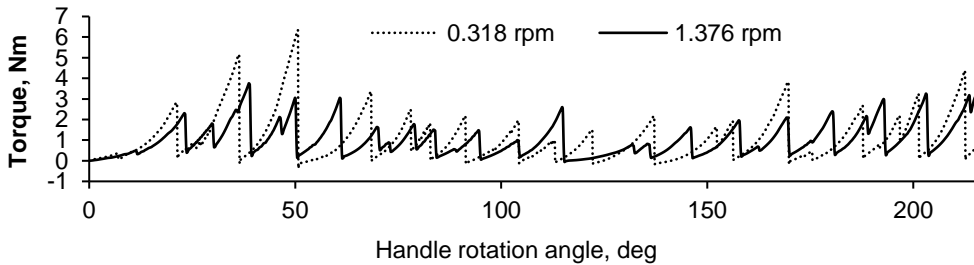


Figure 12. Required torque to increase the slot width between belt pulleys for 2nd generation with two regulating speeds.

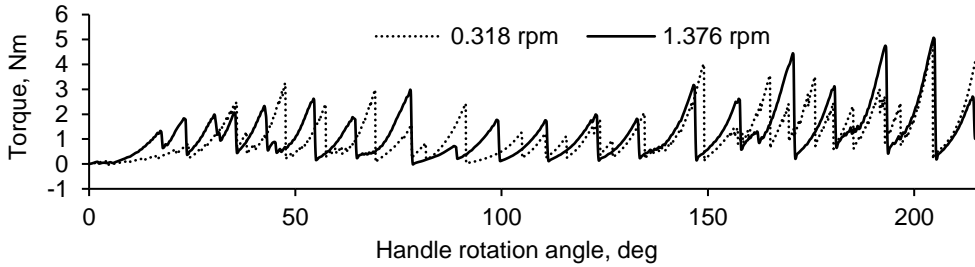


Figure 13. Required torque to decrease the distance between belt pulleys for 2nd generation with two regulating speeds.

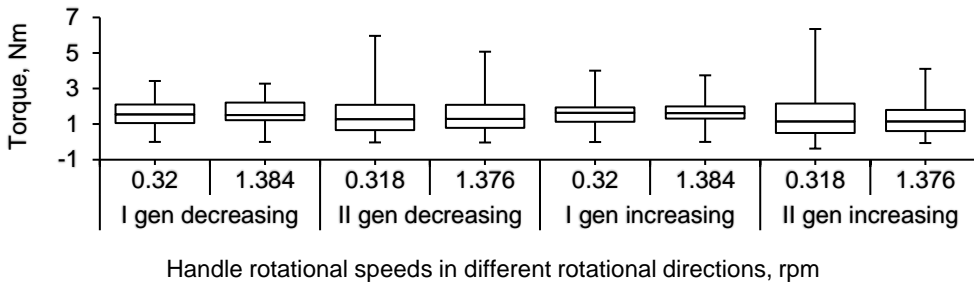


Figure 14. Summarized results for required torque to regulate the slot width between belt pulleys.

Obtained test results for required torque to regulate slot width between belt pulleys show that:

1. With 1st generation the required torque to regulate is maximum at the medium slot width when decreasing or increasing the slot width between belt pulleys.
2. With 2nd generation the required torque to regulate is stepped because the thread surfaces of 3D printed parts are also stepped, not smooth. Every step starts with smooth rise and ends with rapid decrease.
3. According to test results the 2nd generation maximum required torque for regulate is higher than 1st generation. With 2nd generation 6.35 Nm is required when increasing slot width at rotational speed 0.318 rpm but with 1st generation 4.01 Nm is required when increasing slot width at rotational speed 0.32 rpm.
4. Mean required torque to regulate is smaller with 2nd generation in both regulating directions and with both rotational speeds.
5. 2nd generation required torque to regulate dispersion is bigger than it is with 1st generation with both regulating speeds and direction as it is presented in Table 1 (raw-data is obtained from Instron tensile testing system and standard deviation is calculated in MS Excel).
6. For both generation faster regulating speed decreases required torque to regulate dispersion and it's maximum value.

Table 1. Standard deviations of required torque for regulating distance between belt pulleys at different regulating speeds for 1st and 2nd generation

	1 st gen decreasing		2 nd gen decreasing		1 st gen increasing		2 nd gen increasing	
	0.32	1.384	0.318	1.376	0.32	1.384	0.318	1.376
	rpm	rpm	rpm	rpm	rpm	rpm	rpm	rpm
Standard deviation, σ	0.79	0.75	1.04	1.00	0.84	0.72	1.23	0.82

In conclusion, it can be said that 2nd generation fixes the biggest problem that 1st generation has. 1st generation belt pulleys’ backlash relative to the fixing point is a maximum of 10.57 mm but 2nd generation has a maximum belt pulleys’ backlash relative to the fixing point of 2.31 mm. Desired backlash relative to the fixing point should be maximum of 0.5 mm at all slot widths. But on the other hand 2nd generation has some new problems. Test results show that the technology that is used to prototype core and sleeve for 2nd generation don’t suit very well in this case and more suitable technology must be used. It is essential to ensure smooth thread surface finish and smaller clearance between core and sleeve threads to avoid the accumulating backlash between two neighboring belt pulleys and ensure more even and lower required torque to regulate slot width between belt pulleys. Because of required clearance between 3D printed parts, backlash between two neighboring belt pulleys is bigger than it’s should be and it depends on slot width between belt pulleys. Desired backlash between two neighboring belt pulleys should be maximum of 0.5 mm and it should not be dependent on slot width between belt pulleys. Decreasing clearance between core and sleeve will have positive affect on belt pulleys backlash relative to the fixing point and especially on backlash between two neighboring belt pulleys. Overall 2nd generation technical solution showed promising results and has more potential than 1st generation.

CONCLUSION

This paper compares technical characteristics of two patented technical solutions of smoothly adjustable drum and brings out their pros and cons. Main constructional differences are:

1. 1st generation key structure is single one-piece steering shaft with right–hand and left–hand guiding grooves with variable step while 2nd generation has multiple sets of cores and sleeves to regulate distance between belt pulleys.
2. 2nd generation has improved pipe-shaped casing construction and preparation method.

Named 2nd generation developments has following effects:

1. Two extra fixing points to every 2nd generation belt pulley to the key structure is added compared to 1st generation.
2. The outer diameter of 2nd generation pipe–shaped casing’s is constant across it’s length.
3. Belt pulleys’ average backlash relative to the fixing point of 2nd generation is smaller. Maximum belt pulleys’ backlash relative to the fixing point decreased by 8.26 mm.
4. Backlash between two neighboring belt pulleys of 2nd generation is greater than that of 1st generation and it depends on slot width between belt pulleys.

5. Required torque to regulate slot width between belt pulleys of 2nd generation is greater and stepped.

Results show that the last two negative effects of the 2nd generation are caused by the peculiarities of the chosen prototyping method for the key structure and these can be solved by using more suitable manufacturing method. Further research with 2nd generation is necessary to study if these arguments are true.

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