IMPROVING THE DRIVE BELT CLEANING SYSTEM FOR THE POSITIVE FEED MECHANISM OF CIRCULAR WEFT KNITTING MACHINE: A NOBLE APPROACH

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Abstract: *The yarn delivery rate required to knit fabric with a given stitch quality in a multi-feeder circular knitting machine is generally based on the drive belt speed of a positive yarn feed system. Even if the diameter of drive wheel (also known as Quality Adjustment Pulley (QAP) or Variable Diameter for Quality (VDQ) Pulley) of such system is well adjusted to maintain the required belt speed through positive drive, the stitch length measured on the fabric may not remain uniform as production continues. A key reason for this variation is the growing lint accumulation inside QAP that causes changing circumference of QAP gradually. Such deposition of lint may also occur on other parts of the yarn delivery system causing fluctuation in yarn tension and yarn delivery rate from different feeders, which ultimately causes fabric defect. To counteract such problem a typical brush associated cleaning system has been incorporated into some knitting machines by the manufacturers, which also possesses some inherent limitations. In this study, a noble approach has been carried out to develop an alternative cleaning tool for lint removal from the QAP system using compressed air. Further investigation through this study showed that the developed device exhibits better cleaning performance and is cost-effective than the traditional brush-shelf type cleaning apparatus.*

Keywords: *knitting, stitch length, QAP, lint/fluff, compressed air.*

1 INTRODUCTION

When a multi-feeder circular knitting machine knits a fabric, yarn ends from different packages are supplied to needles arranged around the cylinder of that machine. A number of knitting cams positioned around the cylinder define the travel path of the needles. The needles should receive a certain quantity of yarn supplied per revolution of the knitting machine for a smooth knitting process. The amount of yarn, supplied to the needles of a circular knitting machine, determines the quality of the fabric being knitted. To knit a denser fabric, the amount of yarn fed to the needles per revolution of the knitting machine is decreased and vice versa to knit a lighter fabric. Therefore, it is imperative to control the rate at which yarn is fed to a knitting machine in order to maintain the quality of knit fabrics.

In the negative feed system, the needles pulled yarns directly from yarn packages and this system has some serious drawbacks. For instance, the yarn feed rate and the tension of yarn from different packages are varied due to the relative spatial locations of the packages with respect to the circular knitting machine [1]. This varying yarn tensions and feed rates were the reasons for inconsistent product quality as well as low productivity through such feed systems. In order to solve this non-uniform feed rate problem, positive yarn feed system had been developed where yarn is fed to the needles at a controlled rate [1]. More specifically, a number of positive feed units, coupled with the motor through a belt and a drive wheel (Figures 1 and 2), can pull exact amount of yarn from yarn packages to be supplied to needles. This same amount of yarn then wraps around the positive feed wheels and, is subsequently distributed to needles (unlike the direct feeding of yarn to needles). Yarn delivery continues only when the positive feed units are rotating. The drive wheel is adjustable to differentiate the rotation rate of the positive feed units, and consequently, to adjust the amount of yarn supplied to needles. Hence, it is very much interrelated with fabric quality and consequently named as the quality wheel or quality pulley.

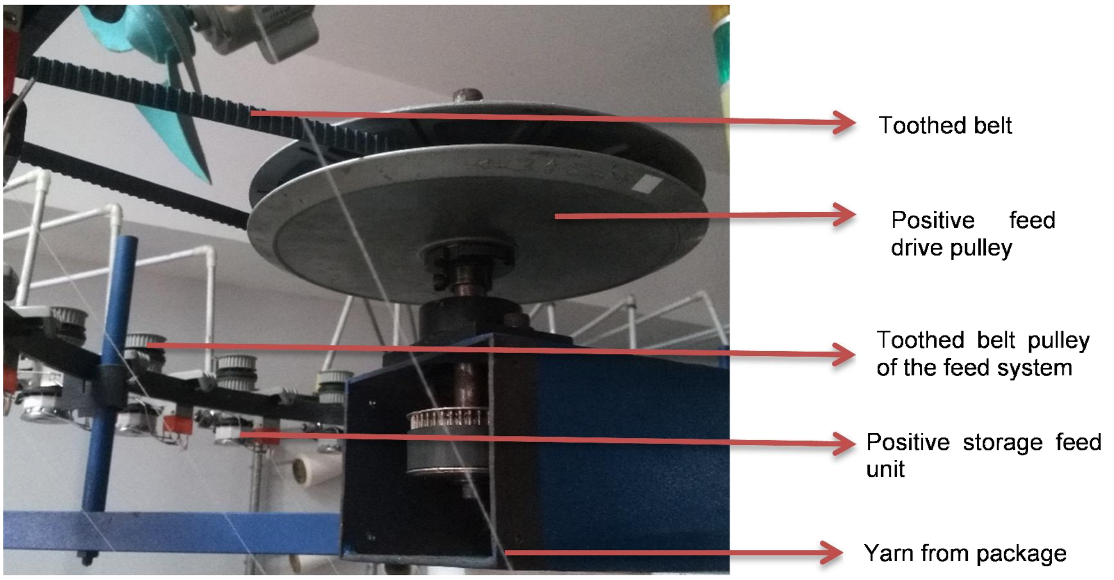

Figure 1 Drive pulley and toothed belt based positive storage feeding

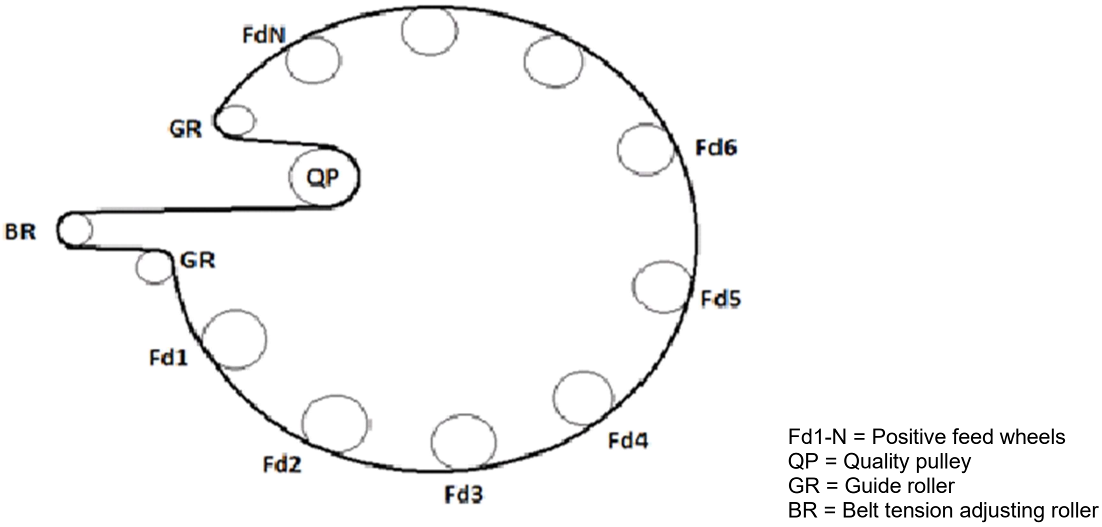

Figure 2 Schematic diagram of positive storage feed system [2]

A quality wheel, also known as Quality Adjustment Pulley (QAP) or Variable Diameter for Quality (VDQ) pulley, is illustrated in Figures 3-5. The quality wheel comprises of upper and lower plates with multiple movable segments between plates along with a lock nut to keep them in place. The upper plate includes a helical groove, while the lower plate includes radial grooves. The inner diameter of the quality pulley is adjustable to vary yarn feed rate. To increase the fabric areal density (e.g., Grams per Square Meter [GSM] or Ounces per Square Yard [oz/yd^2]), yarn supply is reduced by decreasing the inner diameter of the quality pulley through scrolled segments.

This results shorter stitches and hence denser fabric. In addition, couliering depth has to be reduced from cam box, to control high yarn tension caused by decreased yarn delivery. The couliering depth, that expresses the kinking of yarn into a needle loop and the subsequent knock-over of the old loop [3], can be controlled by adjusting the vertical position of the stitch cam to pull a longer or shorter loop. However, in case of positive feeding, the role of such adjustment is to bring tension balance on the feed yarn rather than controlling loop length.

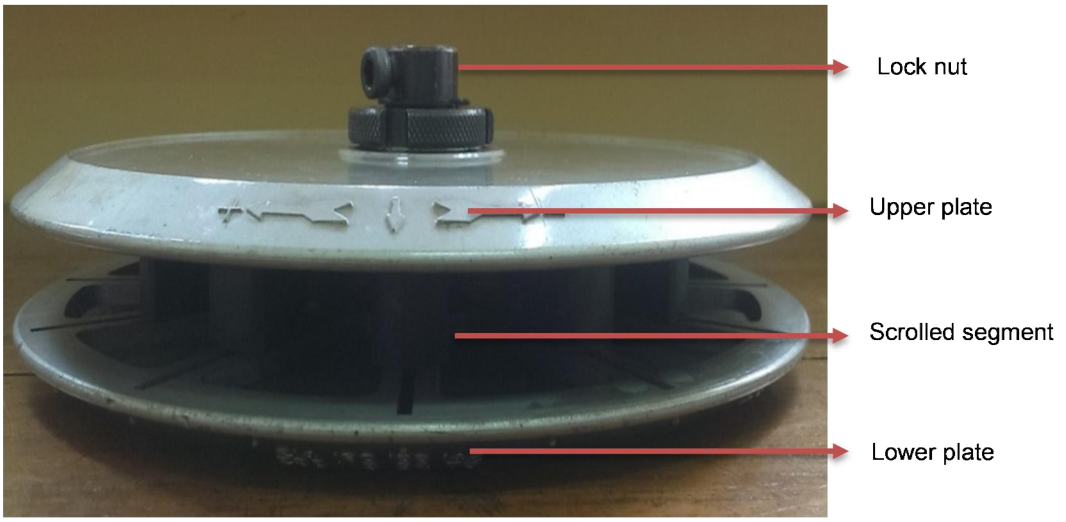

Figure 3 Quality Adjustment Pulley (QAP)

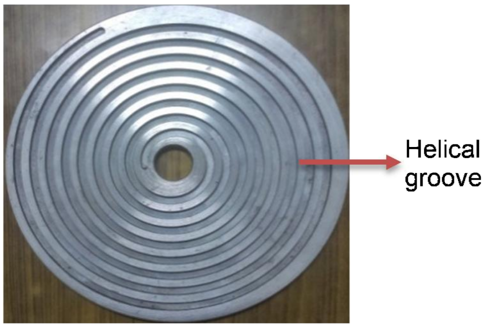

Figure 4 Inside view of upper plate of QAP

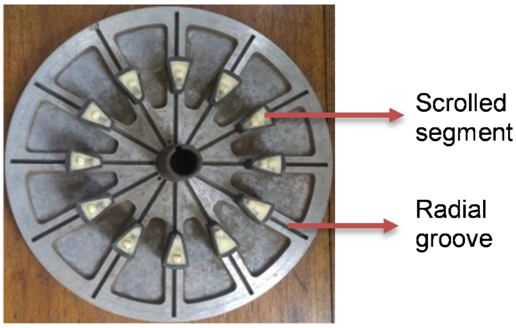

Figure 5 Inside view of lower plate of QAP

It is a common knowledge that the environment of a knitting floor is generally dusty with loose short fibers (i.e., lint), particularly when processing spun yarns. These dusty matters, sometimes known as fly, are sticky in nature, can be carried by the timing belt (Figure 6), even can be deposited and packed inside the grooves of toothed belt pulley. This fly accumulation eventually leads to slippage of toothed belt over toothed belt pulley, resulting poor control of positive feeding system. Moreover, such lint/fluff deposition may gradually grow inside the QAP (Figure 7), which apparently results a shift in pulley diameter and consequent variations in stitch length, even though the positive feed system operates at a fixed speed [4]. Furthermore, the increased belt tension due to the movement of belt over dust/lint deposited surface makes the belt prone to wear and tear and reduces its desired lifetime. Therefore, lint accumulation on yarn delivery system is quite warning and must be avoided to knit fabric with consistent quality.

Figure 6 A continuous QAP belt/timing belt [5]

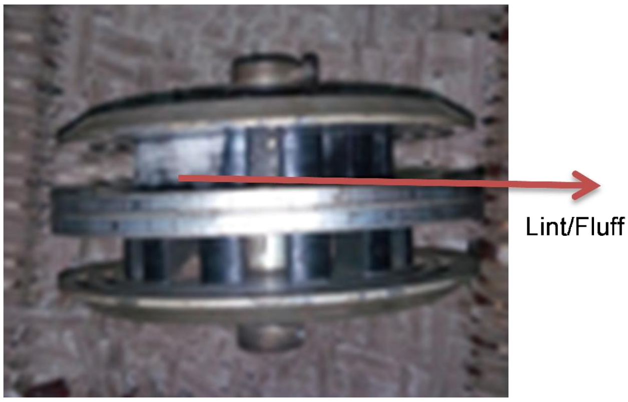

Figure 7 Fluff deposition inside QAP

Unfortunately, cleaning apparatus/methods for QAP system are quite rare till now and the effectiveness of the available one (a typical brush-based system) is questionable. While working in the knitting industry, the researchers observed and witnessed rapid deterioration of the cleaning performance of such brush-based devices. Eventually, it contributed to yarn tension and stitch variation and subsequent generation of two particular fabric faults, i.e. streakiness (Figure 8) and variation in fabric areal density. Both streakiness, i.e. narrow extended unintentional stripes [6], and variation in areal density throughout the fabric roll, would reduce the expected performance of the knitted fabric and could be a reason for customer dissatisfaction. Therefore, maintaining consistent yarn tension and stitch length throughout the knitting operation is imperative for the right quality of fabric. As a part of such effort, QAP belt cleaning system should be highly functional. Therefore, the purpose of this study is to develop a functionally better and cost-effective lint/fluff removal device for the QAP belt than the existing brush-based system. The system should resist the deposition of lint/fluff on the QAP system quite successfully.

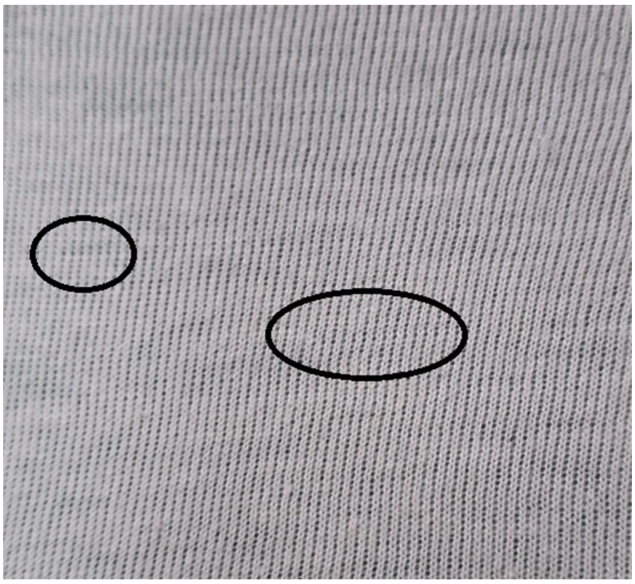

Figure 8 ‘Streak’ in grey cotton-knitted fabric

1.1 State of different cleaning systems for knitting machines

Numerous research works, mostly through patents, have been carried out over time to protect different parts of a knitting machine from environmental substances. Various dust/lint/fluff removing means (e.g., compressor and conduit, housings, fluid ejecting nozzle, air jet nozzle, filter, suction, blower, fan, airstream, etc.) were developed and are chronologically reviewed in this section.

Shortland’s invention comprised of a compressor and conduit to transmit compressed air at a relatively low pressure [7]. The compressor air directed to different machine parts to keep them clean from lint or fluff. Schmidt proposed housings in which the dust is raised and swirled up by an air steam and then, sucked off by a suction system [8]. The deposited dust is further collected in a dust bag or thrown away into the open air. The invention was based on the principle of raising the dust using a blower at the spot where it collects, followed by sucking the dust off through a suction fixture. This method claims the advantage of taking air from the blow tubes directly to relatively inaccessible spots without any damaging effects on the threads and stitch forming tools when the dust is moved from the spots.

Abrams and Tetrault showed a typical apparatus that was designed for blowing lint and other foreign objects away from the critical parts of the knitting machines with top creel arrangement [9]. Abrams, in another study, invented a lint removing device with fluid ejecting nozzles to prevent the accumulation of lint on the critical parts of the machine [10]. Nurk proposed a dust-collecting system for a circular knitting machine that has a needle cylinder and loop-forming instrumentalities which form loops along an annular loop-forming zone. A number of suction nozzles circles around the annular loop-forming zone to collect dust and fluff from the zone [11].

Yorisue and Morimoto invented a waste fiber removing device [12] with air jet nozzle which is flexible enough to impart a fluttering motion. The air jet nozzle is either stationary or rotating to prevent the accumulation of lint on various adjacent parts of the knitting machine. Rovinsky and Meszaros described a knitting machine attachment using pressure air that flow through a number of flutter tubes to control the accumulation of lint [13]. Each tube construction consists of an inner circular bore encircling elliptical wall which causes a flutter or pivotal traverse in a specified plan or path where lint is likely to accumulate.

Igarashi and Iida described a collector/remover of dust in knitting machine [14]. Fibers accumulated adjacent to the knitting zone and to yarn feeding devices of the knitting machine is blown to a filter next to the top of the machine. The lint is removed from the filter by a rotatable filter cleaner and then, is transported by suction to a vacuum device outside of the machine. In their (Igarashi and Iida) another research, an apparatus with suction/blowing attachment causes the fiber waste generated at the upper part of the knitting section moving upwardly through the suction duct associated with the suction-blowing segment [15]. Mutually spaced fiber waste collectors upon the knitting machine and on the creel of a knitting unit collect fiber waste, which is then withdrawn by a fiber waste remover. The waste remover is selectively connectable to different fiber waste collectors. Sensors can detect when the fiber waste collected by the collectors when the waste exceeds a predetermined amount.

An injection nozzle, invented by Izumi, is located on a rotating cylinder of a circular knitting machine to remove dust, lint and waste fibers as well as lubricating the knitting unit. The nozzle, located between the sinker cap and sinker cam, includes a tip opening located adjacent to the knitting unit. This nozzle also includes a receiving end located opposite to the tip opening. Mist-oil and air discharge at the tip opening of the injection nozzle for cleaning and lubricating the knitting unit [16]. Tsay showed a dust blower, mounted at the center of the circular knitting machine, to blow dust and fluff away from the annular loop forming zone. The dust blower includes a rigid guide tube and a swivel nozzle head. The rigid guide tube is connected to a compressed air source and rotates horizontally by a constant speed motion. The swivel nozzle head is mounted on one end of the rigid guide tube and rotates vertically when compressed air is driven out of its radial nozzles [17].

Baumann developed a fan-based cleaning system with a rotating arm, which is only suitable for the dimensions of circular knitting machine (not for flat-bed knitting machine) [18]. For double jersey circular knitting machine, Gutschmit explained some means for deterring lint and debris accumulation on the knitting elements [19]. According to his claim, the needle and dial slots can be significantly cleaned by enclosing an annular air chamber spanning between the cylinder and dial, and by delivering a pressurized air steam into the chamber. The air stream will blow lint, debris and contaminations away from the critical knitting elements (e.g. needles and sinkers) and prevent the accumulation of such materials within the cylinder and dial slots. Willmar, Sickinger and Berwald introduced a dust removal device which contains air distribution channels. These channels, configured in segments, are connected to a compressed air source via radial air supply channels [20].

From above discussion, it can be concluded that researchers and/or inventors used mainly two basic techniques- lint collecting and lint blowing means to control lint. Lint collecting technique was basically a lint suction system whereas lint blowing technique involved a system that applies jet of compressed air. Though some existing technologies (e.g., brush cleaning) incorporate the indirect way of keeping QAP away from dust via cleaning of QAP belt but, none of these previous studies mentioned any means of keeping QAP clean directly using compressed air. It is quite expected that an apparatus using pressured air flow will be able to obviate the accumulation of lint or fluff in any critical point of the knitting machine efficiently.

1.2 Traditional brush-based cleaning of QAP belt

Friction between yarn and various knitting machine's parts (e.g., yarn guide, feeder) with which the yarn comes into contact causes fibers breakage within the yarns. These broken as well as waste fibers are separated from the yarn and gets accumulated as lint or fluff in the contacted parts and adjacent areas of the machine. This fiber waste as well as other environmental dirt particles may also be attached on the toothed belt, carried away inside the QAP, and eventually accumulated over some scrolled segments. A significant amount of such elements (lint/dirt/fluff) deposited over the scrolled segments may create eccentricity increasing the circumference of the quality pulley. The increment of circumference leads to faster surface speed of the quality pulley and, subsequently increasing yarn delivery rate than the desired one. The periodic variation of yarn delivery rate due to the build-up eccentricity in QAP may also result fluctuation in yarn input tension and thereby, making the yarn delivery process unstable. A portion of the generated waste fiber during the knitting process may be collected on the grooves of some QAP belt pulleys through the belt, resulting faulty positive feeding through feed units. To overcome such problems, some knitting machines are provided with a typical brush-based cleaning apparatus (Figure 9) for the QAP system. As shown in figure 9, two rotating brushes attached in a brush-self are used to clean both sides of the QAP belt. Being surface driven by the moving QAP belt, the brushes remove fly or dirt from the belt.

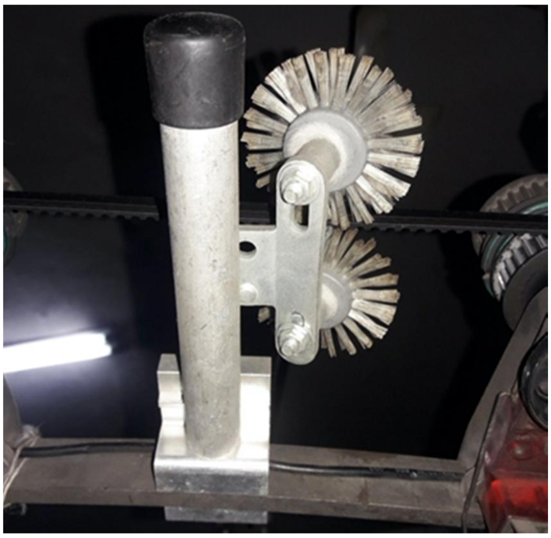

Figure 9 Single brush-shelf for circular knitting machine

1.3 Significance of the study

The typical brush-based cleaning apparatus for QAP system has some practical limitations. Firstly, the brushes are highly prone to wear on bristle side due to friction with moving belt. Secondly, the brushes get clogged frequently with dust//lint during operational hours and need frequent attention from the knitting machine operator.

Furthermore, the frequent manual handling of this cleaning aid might not fit ergonomically for all operators particularly those having comparatively shorter physical postures. Therefore, a need for an alternative cleaning apparatus is quite justified. On basis of previous studies, it may be assumed that a compressed air-based cleaning system would overcome the existing limitations of brush-based cleaning as well as show better cleaning performance. Therefore, the purposes of this study are i) to develop a compressed air-based cleaning system, and ii) to compare the cleaning performance and operating cost between brushed and air-based cleaning systems.

2 MATERIALS AND METHODS

2.1 Constructional elements

To develop a prototype compressed air-based cleaning apparatus, cheap and available material components have been used. Soft flexible plastic pipes with roller clamps have been used as conduit means. Polyvinyl Chloride (PVC) based board and channels have been utilized for housing. Hard plastic fittings like Tees and Elbows together with metal screws were used as joining aids. The device is developed in such a way that it can be mounted on the feed-units holder ring conveniently.

2.2 Constructional method

A sketch of the desired prototype device is shown in Figure 10. The width and total thickness the QAP toothed belt (not mentioned in the sketch) that would undergo cleaning, were considered as 10 mm and 3 mm respectively following the toothed belt dimensions of the renowned Memminger-IRO drive systems [5].

As in Figure 10, a base plate (1) is attached to a shaft (2) by screw (3a, 3b) to hold the entire device. An upper base plate (4) is attached by screw (5a, 5b) above the first base plate (1) for reinforcement purpose. These base plates (1, 4) are made of PVC composite board. A tee (6) is placed in the center of the upper base plate (4) to join pipe-segments (7, 8). With the pipe-segments (7, 8), two 90° elbows (9, 10) are attached. Another two PVC pipe-segments (11, 12) were attached with other ends of the elbows (9, 10). Two tees (13, 14) were joined on both open ends of the PVC pipe-segments (11, 12). At the top openings of the tees (13, 14), another two pipe-segments of PVC pipes (15, 16) were attached. On the other end of these PVC pipe-segments (15, 16), two elbows (17, 18) were attached. Air nozzles (19, 20) attached with flow tubes (21, 22) were incorporated with the side openings of tees (13, 14). Other air nozzles (23, 24) attached with flow tubes (25, 26) were incorporated with the openings of elbows (17, 18). The tubes (21, 22, 25, 26) act as conduit means and are connected to the air distributor of the machine. A roller clamp (not shown in the diagram) was used with each flow tube (21, 22, 25 and 26) to regulate the rate of air flow.

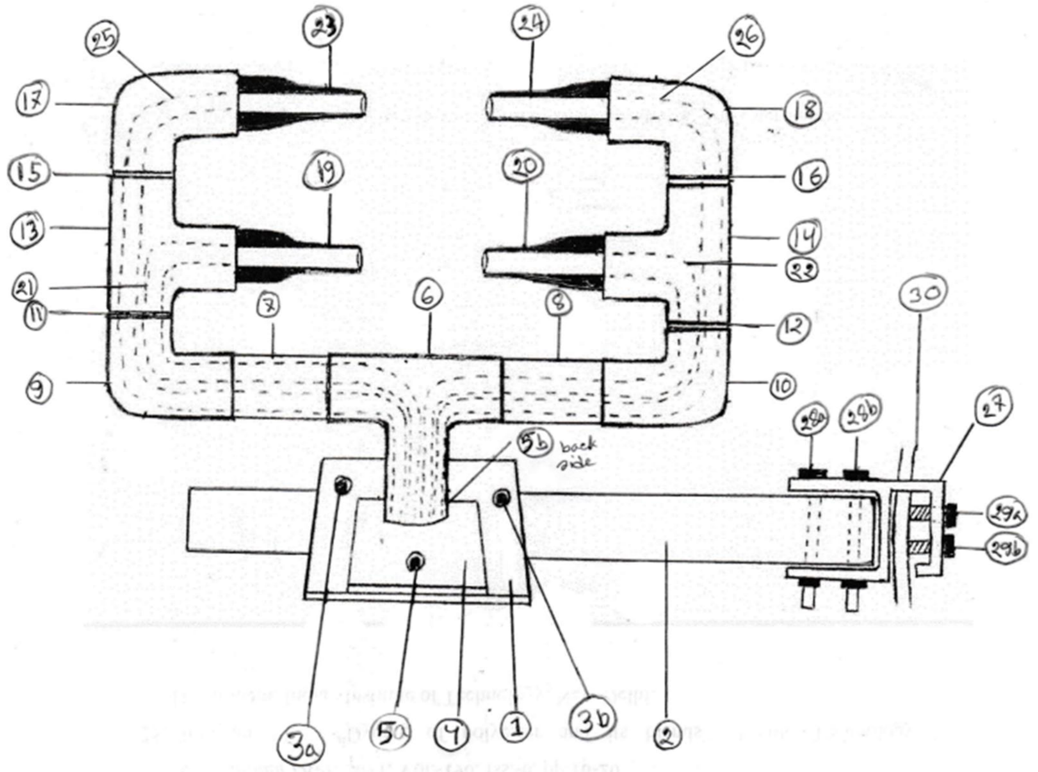

Figure 10 A drawing of the proposed air nozzle based QAP belt cleaning apparatus

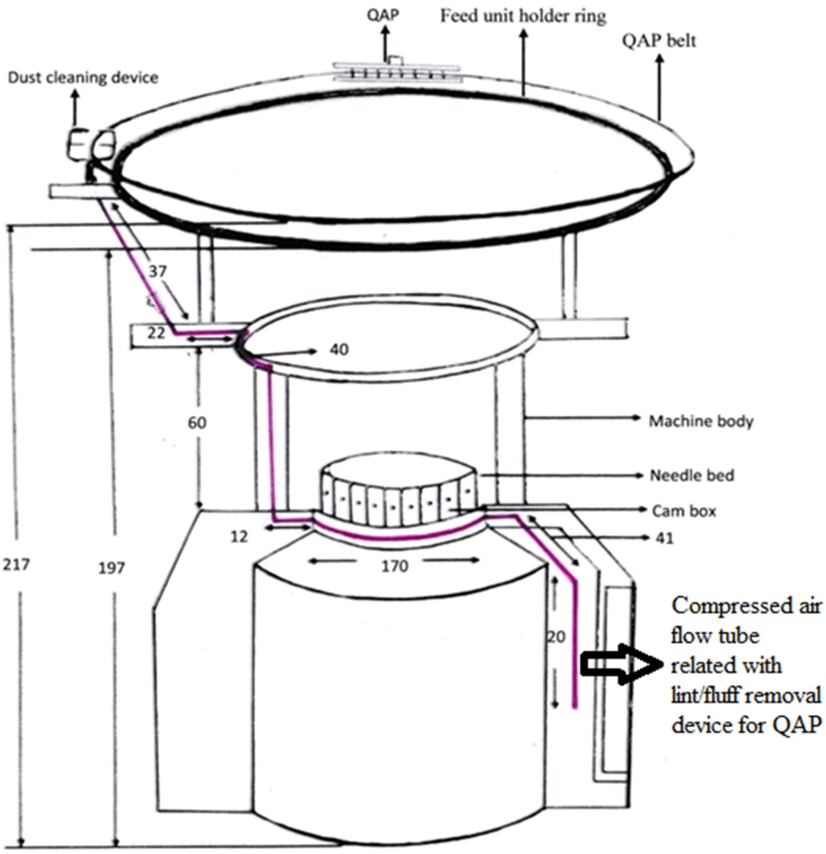

Figure 11 Proposed attachment of a compressed air-based lint removal device on a circular knitting machine with QAP based positive feed system (all measurements are taken in centimeters)

Typical diameters of PVC pipe-segments and nozzles are around 12.50 mm and 5 mm respectively. The distance between two face-to-face nozzles was kept at 23 mm so that the belt remains 10 mm away from any corresponding nozzle. This gap of 10 mm has been chosen according to the commonly practiced setting of lint blower (needle to air nozzle end) found through the periphery of needle cylinder of an industrial circular knitting machine. Based on the study by Torlach (1999), the compressed air pressure was maintained at around 210 KPa (around 2 bar) through air regulator unit [21]. It is because the air jets directed to the belt passing between face-to-face nozzles are strong enough to blow away attached lint without any damaging effect to belt or making any deviation to the belt's running condition. The position of whole base plate (1) can be adjusted somewhat by tuning the position of screws (3a, 3b). The shaft (2) is joined with feed unit holder ring (30) through a gripper (27). The gripper (27) is fixed with the shaft (2) by screws (28a, 28b). Two other screws (29a, 29b) are set at other side of the gripper (27). These screws (29a, 29b) are used for firm fitting of the gripper with the ring (30). A typical diagrammatic set-up for this device on a circular knitting machine (Orizio-Johnan, E 24) is shown on Figure 11.

3 RESULTS AND DISCUSSION

3.1 Installation of the device

An image of the developed prototype apparatus is shown in Figure 12. The device was first installed on a circular knitting machine in a lab setting for a trial run (Figure 13).

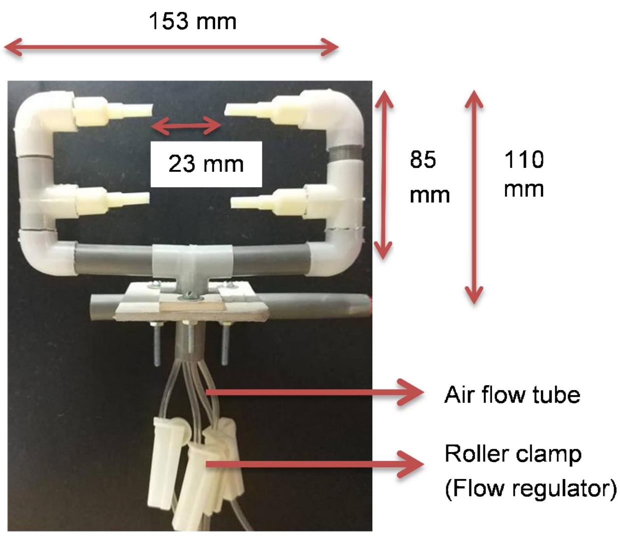

Figure 12 An image of the developed lint removal device for the QAP belt

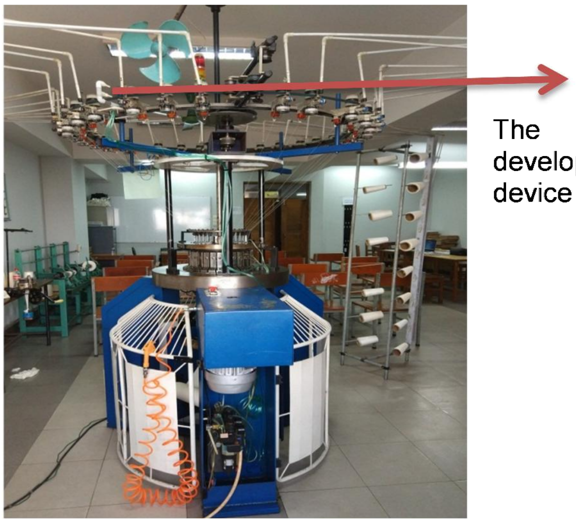

Figure 13 The newly developed lint removal device attached to a knitting machine

3.2 Comparative cleaning performance between brush-based cleaning system and compressed air-based cleaning system

A comparative measurement of cleaning performances between brush-based cleaning system and compressed air-based cleaning system on the basis of dirt/fluff deposition over the scrolled segments inside QAP was carried out in an industrial environment. A circular knitting machine from a renowned knitting mill in Bangladesh was used for the intended purpose. In order to compare the cleaning performances, both the brush-based and compressed air-based cleaning devices were attached individually with same knitting machine [24 gauge, 34-inch (86.36 cm) diameter, 2556 needles, and 102 feeders] to produce the same single jersey structure fabric. Same yarn [60/40 cotton/viscose, 30/1 Ne (19.68 Tex)], same stitch length (2.72 mm) and other identical knitting parameters were maintained throughout the production hours consistently. Before attaching each of these cleaning devices, the scrolled segments inside QAP were cleaned properly, so that no dust/fluff can be pre-existed. Related data was collected for two consecutive days so that any significant change in room atmospheric condition and its effect on lint accumulation could be avoided.

For the brush-based cleaning device on day one for 24 hours (between 2 PM to 2 PM) duration, total actual production, total mass of dirt/fluff collected over the scrolled segments inside QAP, and mass of dirt/fluff collected over the scrolled segments inside QAP for 1 kg production of knitted fabric were 312.50 kg, 0.0818 gm and 0.00026 gm/kg respectively. Similarly, these outcomes for the compressed air-based device were 323 kg, 0.0601 gm and 0.00019 gm/kg respectively. Around 29 percent of less dust deposition was observed over the scrolled segments inside QAP due to installation of compressed air-based cleaning device instead of brush-based cleaning device. The outcomes of this study support better cleaning performance of compressed-air based device than that of the brush-based cleaning device. It is expected that the performance will be improved exponentially over a longer duration as less dirt/fluff deposition facilitates lesser further dirt/fluff deposition inside the QAP. Table 1 summarizes the comparative measurement of cleaning performances.

Since the compressed air-based cleaning apparatus is contactless to the QAP belt, any friction induced damage is impossible. Hence, frequent cleaning of QAP is not needed rather operator has to be aware of any leakage of compressed air. On the other hand, the belt, particularly the brushes are highly prone to wear on bristle side due to continuous friction between moving belt and brushes in the brush-based cleaning system. Frequent cleaning of brushes is required as dust collected by the brush causes jamming inside bristles resulting reduced cleaning efficiency.

Table 1 Comparative cleaning performances between traditional brush-based cleaning device and the developed compressed air-based cleaning device

Particulars obtained for Brush-based cleaning device	Particulars obtained for Compressed air-based device	Cleaning performances differences	Finding
*Production date and time =23/12/18 to 24/12/18 (2pm to 2 pm) *Avg. temp. = 25.5°C and R.H. 55% (approx.) respectively *Actual production=312.5 kg *Mass of lint/ fluff collected over the scrolled segments inside QAP during the production hours = 0.0818 gm *Mass of dirt/fluff collected over the scrolled segments inside QAP for 1 kg production of knitted fabric = 0.00026176 gm	*Production date and time =24/12/18 to 25/12/18 (2pm to 2 pm) * Avg. temp. = 25°C and R.H. 56% (approx.) respectively * Actual production=323 kg *Mass of lint/fluff collected over the scrolled segments inside QAP during the production hours =0.0601 gm *Mass of dirt/fluff collected over the scrolled segments inside QAP for 1 kg production of knitted fabric = 0.000186068 gm	0.0000757 gm less lint/fluff deposition inside QAP for 1 kg production of knitted fabric by the compressed air-based cleaning device over the selected time period of 24 hours	Due to installation of Compressed air-based cleaning device instead of brush-based cleaning device around 29 % less dust deposition was observed over the scrolled segments inside QAP

Most importantly, this frequent cleaning is not ergonomically feasible for workers, specifically of Bangladesh origin. The average height of Bangladeshi male is around 167.7 cm [22] and female is around 150.6 cm [23], whereas the brush-shelf/feed unit holder ring of a large diameter circular knitting machine is located more than 180 cm (like in Orizio-Johnan machine) above the ground.

3.3 Comparative cost analysis

To determine the feasibility of this study, a comparative cost analysis between traditional brush-based cleaning system and compressed air-based cleaning system has been conducted. After the successful trial run in lab setting, the developed device was attached to a knitting machine of a renowned knitting mill in Bangladesh to gather industry scale data. Therefore, all cost relevant to this experiment was calculated in a local currency (BDT), which then can be converted to USD (USD 1 = BDT 85 approximately) or EUR (EUR 1 = BDT 95 approximately).

Operating cost

The cost of compressed air consumed by the developed device was determined based on per unit cost of compressed air. The cost/m^3 of compressed air (at 10 bar) was calculated as BDT 0.67 using (1) (based on 100 percent compressor motor efficiency, 55 KW motor capacity, electricity cost of 8.15 BDT/kWh, 80 percent of operating hours running as fully loaded state, and volume of generated compressed air at 10 bar = 9.51 m^3/min).

The cost of compressed air per nozzle per year consumed by the developed device was calculated as BDT 1,305 using (2) (considering average knitting machine running time = 21 hours/day indicating the efficiency of 87.5 percent, yearly working days = 298 [excluding common official holidays of Bangladesh], distance between air nozzle to belt = 10 mm [indicating the common distance maintained for cleaning of knitting elements through compressed air jet], diameter of air nozzle = 5 mm, and average velocity of compressed air ejected from the nozzle, V = 22 m/s [measured by an anemometer, as shown in Table 2]).

From further calculation, it can be estimated that the developed device with four nozzles (applicable for a two QAP-based yarn delivery system) can cost BDT 5,250 and share about 0.19% of total cost need to generate compressed air by the compressor. On the other hand, cost evaluation for brush-based apparatus was done mainly based on the information provided by the authorized local agent of Memminger-IRO, the manufacturing company of this particular device. Four pieces of brush are required for a two QAP-based positive feed system, and the expected lifetime of each brush is one year, according to the supplier's warranty. As in this cleaning system, only brushes are required to be replaced when damaged/consumed, yearly cost for such system with four brushes stands at BDT 5,600 (price/brush = BDT 1,400). Therefore, annual cost for the developed device (i.e., BDT 5250 or USD 61.76) is 6.25% less than that (i.e. BDT 5,600 or USD 65.88) of the traditional brush-based cleaning device.

Device price

The asking price of a typical brush-based cleaning system (entire brush-self system with four brushes) was BDT 15,000 or USD 176.47(according to the supplier's invoice). On the other hand, the manufacturing price for the developed device was around BDT 1,650 or USD 19.41 (including parts and BDT 1,000 labor charge). As the device was built on prototype basis, the manufacturing components were purchased locally and hence, the reason for low cost. However, it was not evaluated in commercial scale as well as selling price is not considered in this study. Nonetheless, it is expected that the developed system will still be cheaper in price when it will compete with the brush-based apparatus through the same platform.

$$\text{Compressed air cost in BDT} = \frac{hp\ x\ 0.746\ x\ operating\ hours\ x\ \frac{BDT}{kWh}\ x\ (time\ \%)\ x\ (full\ load\ hp\ \%)}{Motor\ efficiency} \quad (1)$$

$$\text{Compressed air consumption per nozzle per year } = V\pi\left(\frac{d}{2}\right)^2 \times 60 \times 60 \times 21 \times 298\ m^3 \quad (2)$$

Table 2 Determination of the rate of air flow that will be ejected from a nozzle of the developed device

Reference position (distance)	Machine	Compressed air pressure [bar]	Air flow rate [m/s]	Average air flow rate [m/s]	Standard deviation
Needle to compressed air ejecting nozzle - end (10 mm)	Orizio-Johnan E 24	2	22.1	22	0.492161
			21.7		
			22.2		
			20.9		
			22.8		
			21.9		
			22.1		
			21.8		
			22.3		
			22.2		

4 CONCLUSION

An extensive root-cause analysis is carried out (as an extended part of this study) primarily for all recognized circular weft knitted fabric defects (e.g., hole, stain, press-off, snag, gout, miss knit, barrè, etc.). Two particular flaws/faults– areal density variation and streakiness have been isolated and scientifically investigated to consider the scope of rectifying them. The purpose of this study lies on conducting a machine modification to minimize the propensity of these two faults, whose root causes are directly related with lint accumulation in the drive wheel and belt based positive feed system of circular knitting machine. Therefore, a new lint removal device using compressed air for the cleaning of QAP belt, has been developed.

Based on the outcome of this study, the developed compressed air-based cleaning system for QAP belt is an excellent alternative to the currently available brush-based cleaning system. The prototype device developed in this study is cheaper, easy to install and operate, and entirely free from the risk of mechanical friction. It does not need any additional supporting system as the air distributor is already available in the machine as an integral part of it. Moreover, using this compressed-air based system eliminates the physical limitation of Bangladeshi circular knitting machine operators or people with short stature while setting up and changing brushed shelf cleaning system. Apart from better cleaning performance, the calculated operating cost of the compressed air-based cleaning system seems to be cheaper if the device is used as a replacement of brush-based cleaning apparatus for QAP belt. Finally, the developed device has been proven effective, convenient and economically feasible along with achieving better cleaning performance. Therefore, it is superior to the traditional device of its type and highly recommended for installation in circular knitting machines having positive feed drives. However, while working with such compressed air-based lint removal system, there is a higher possibility of the removed fiber to be settled upon nearby yarn or machine components. The venti-cleaners of the machine, more specifically the top one, should operate properly during knitting to overcome this.

4.1 Limitations of this study

The findings of this study have to be seen in light of some limitations. Firstly, there is a paucity of research available on the performance of brush-based clean system for the circular knitting machine. Secondly, a reliable source for some compressor related information (e.g., motor efficiency, compressor loading, and unloading duration) was unavailable to the particular knitting mill used in this study. This information was collected from the maintenance department without cross verification, which may lead to some erroneous judgement while calculating the cost of generated compressed air. However, it can be realized that these limitations are not so potential to hamper the research outcome significantly.

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