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Development of a new yarn supply for weft knitting machines to produce innovative knitwear

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ABSTRACT

The increasing demand for technical textiles makes innovations and acceleration of processes necessary. This research paper presents an innovative knitting technology. The technology, which was funded by the European Regional Development Fund as an R&D-project (EFRE-0400310), reduces production time and creates completely novel innovative knitting structures. This paper introduces the validation process of the innovative technology and therefore brings the theoretical considerations into a practical application. The yarn supply technology enables the production of an innovative double-layered fabric on flat and circular knitting machines. This double-faced fabric consists of two single-faced fabric sides which are knitted by a first yarn in the front needle bed and a second yarn in the rear needle bed. These two fabrics are joined by a third yarn knitting in both needle beds in the same carriage stroke. The method ensures that up to three yarns knit in one system pass. Furthermore, a fourth yarn can be implemented to insert a weft yarn. Additionally, the two single-faced fabrics can be produced simultaneously in the same carriage stroke in the front and rear needle beds. In this case, fewer carriage strokes are required for knitting standard structures such as Milano Rib. This structure can be produced one third faster than with conventional methods. The results show that the technology on the circular knitting machine produces good quality knitted fabrics. On the flat knitting machine, however, further research and development are needed to validate the technology.

Keywords
knitting,
plating,
multiply fabric,
innovative yarn supply,
layering,
novel structures

1 Introduction

This paper presents an innovative knitting technology that combines the plating technology with a modified plush yarn supply. The results are completely new types of multi-layered knitting structures.

Plating is one of the most difficult techniques to achieve in knitting production. It is the production of a knitted fabric from two overlapping yarns of different materials or colors. One yarn comes to lie on the face of the knitted fabric, and the second forms the inside or reverse face. For this purpose, the two yarns (ground and plating yarn) must be separated and fed to the needles under correct yarn tensions. The correct feeding is ensured by yarn carriers which insert the two yarns in defined positions: The ground yarn always runs behind and above the plating yarn and is covered by the plating yarn in the double face knit on both sides and in the single face knit only on the upper side. There can also be three yarns arranged one behind the other. In that case, one yarn forms the front of the fabric, the second one the back of the fabric and the third yarn lies between those two [1-7].

In traditional plating, knitting is done with a special plating yarn carrier which places both yarns into the same needles in a specific and controlled configuration. The ADF (Autarkic Direct Feed) technology developed by Stoll offers autarkic individually motorized yarn carriers. These can be programmed to automatically move into the plating and ground positions. Whether knitting with conventional plating yarn carriers or with the autarkic yarn carriers, the ground and plating yarns are always inserted in the exactly same needles. This means that both the plating yarn and the ground yarn always knit the same structure at the same time. Therefore, both yarns have similar yarn consumption [8,9].

Plush or terry is a fabric with yarn loops on one or both sides of the fabric. To create a plush fabric, a special plush yarn carrier is needed. Compared to a standard yarn carrier, a plush yarn carrier is not positioned centrally between the two needle beds. The yarn carrier tip of the plush yarn carrier is positioned above the front needle bed in front of the needles of the rear needle bed. The plush yarn is only inserted into the needles of the front needle bed [10-12].

The special characteristic of the innovative knitting technology presented in the paper is to combine plating with a modified plush yarn supply on both needle beds.

The characteristic of the fabric is that the two plush yarns do not touch each other and yet are firmly connected by the double face structure between them.

This innovative, patent pending technology [13] was validated on flat and circular knitting machines in the course of an R&D-Project.

2 Principle of the innovative technology

A standard yarn carrier (8) (Fig. 1) is in the standard position and inserts the yarn just above the needle cross (L) in the needle hooks (K). Another yarn carrier (6) is positioned on the front needle bed (4). It is similar in structure to a plush yarn carrier. Yarn carrier 6 places the yarn (F1) in the hooks of the needles of the front needle bed. As yarn carrier 6 is positioned in front of the needles of the rear needle bed (5), the yarn is only gripped by the needles in the front needle bed. The same happens in the rear needle bed with a yarn carrier (7). Yarn carrier 7 places the yarn in the needle hooks of the rear needle bed. As yarn carrier 7 is behind the needles of the front needle bed, the yarn (F2) is only inserted in the needles of the rear needle bed [13].

Figure 2 shows how the yarns are inserted in the needles at their maximum height. Yarn F1 is placed on the open latches (Z) (Fig. 1) of the needles of the front needle bed. Yarn F2 is placed on the open latches of the needles of the rear needle bed. Yarn F3 is placed above the needle cross (Fig. 1) in the needle hooks of the needles in the front and rear needle beds.

When the needles lower, the latches are closed. Now there are two yarns in each needle hook. Yarn F1 and yarn F3 are in the needle hooks of the front needle bed, yarn F2 and Yarn F3 are in the needle hooks of the rear needle bed **Fehler! Verweisquelle konnte nicht gefunden werden.**(Fig. 3).

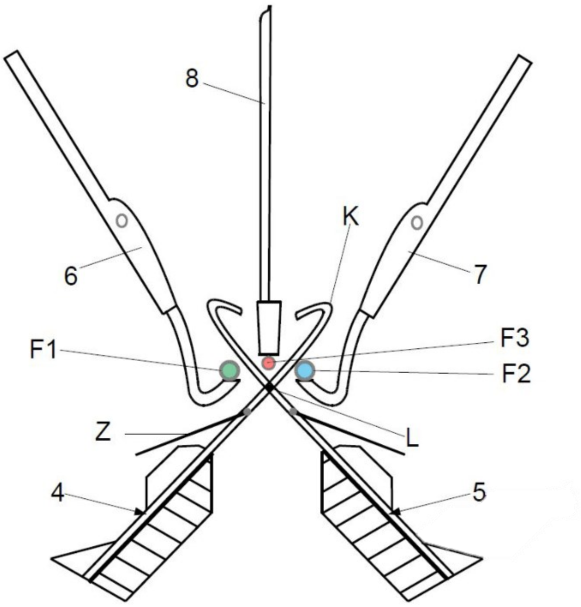

Fig. 1 Machine set-up for the realization of the innovative knitting technology; adapted from WO2020069856A1.

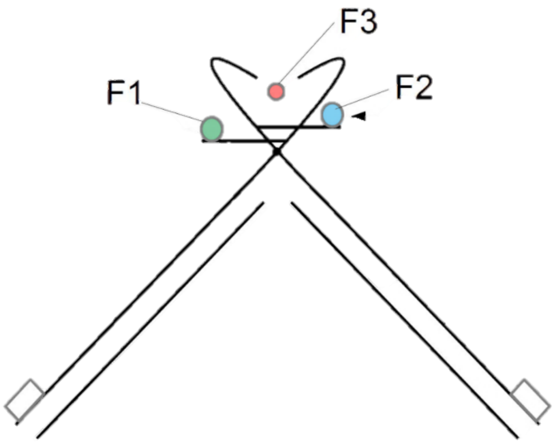

Fig. 2 Inserting the yarns into the needles at their maximum height; adapted from WO2020069856A1.

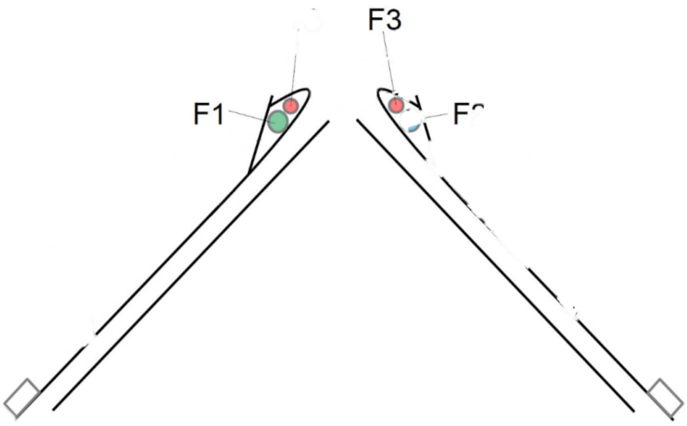

Fig. 3 Inserted yarns after lowering the needles; adapted from WO2020069856A1.

Yarn F3 is knitted by all needles, alternating between the front and rear needle beds. A double face rib structure is created. F1 and F2 are knitted only in the front and rear needles respectively and not in the opposite needle bed. The result is a single face structure (Fig. 4). Lastly, another standard yarn carrier can be used to place a weft yarn between the needle beds.

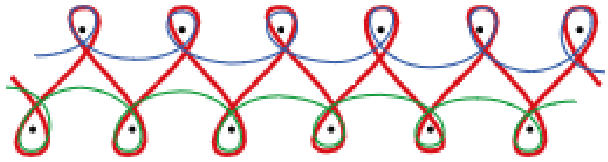

Fig. 4 Needle notation of the innovative knitted fabric.

As indicated above, this construction allows two different uses:

The first application is to knit already known structures, e.g. Milano Rib, with increased productivity. In the standard production of a Milano Rib structure, three carriage strokes (flat knitting machine) or three feeds (circular knitting machine) are needed for one repeat. In contrast to this, the innovative technology offers the possibility of knitting the second and third row simultaneously in one carriage stroke or feed, which enables an increased productivity by 33%.

The second application is to create completely new knitted structures. The result is a double face knitted fabric that is plated on both sides with a single face knitted fabric (Fig. 5).

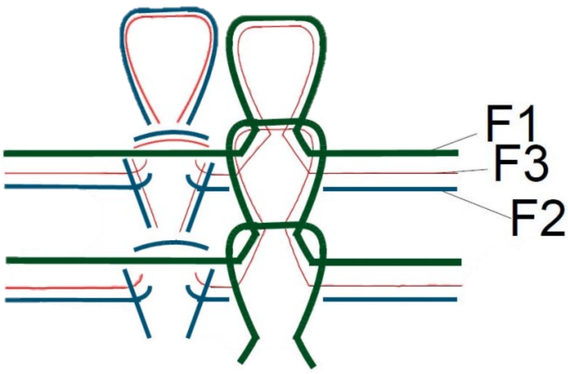

Fig. 5 The knitted structure of the innovative knitting technology resembles a knitted fabric plated from both sides; adapted from WO2020069856A1.

The plating of the innovative knitting technology is different to the conventional plating with a plating yarn carrier. While yarn F3 is knitted in a double face structure, the yarns F1 and F2 are knitted in single face structures.

Using this second application leads to two challenges as both structures are knitted in the same needle:

- double face and single face structures have different yarn consumptions,
- double face and single face structures are knitted at different tightness factors.

With the same settings, a double face structure is usually knitted with a lower tightness factor than a single face fabric, because the distance between two needles from the same bed is commonly lower than the distance between two adjacent needles from different beds. If both a double face and a single face fabric are knitted in one needle, a compromise must be found for the tightness factor. If knitted with the correct tightness factor for a single face structure, too much material of the double face yarn will remain. When knitting with the correct tightness factor for a double face structure, the tension on the single face yarns is so high that the yarn breaks during the knitting process. Therefore, knitting was done with the tightness factor for the single face structures and the yarn tension on the feeder of the double face yarn (F3) was increased. The problem of the yarn building up between the needle beds was minimized slightly, but not completely solved.

As part of the project, prototypes of yarn carriers for a flat knitting machine and for a circular knitting machine were developed. In order to be able to assess the positions of the yarns in the knitted fabric, the same polyester yarns in three different colors were set for the trials. As the used machines (one flat and one circular knitting machine) have the same gauge (E10), the same material was used on both machines. The material is a 100% polyester filament yarn called Waffle by Di.Vè filati. The yarn count is 22 tex. The machines and the tests carried out are described below.

3 Prototype on flat knitting machine

First, a yarn carrier prototype for a motorized flat knitting machine (IBOM/b by Stoll) gauge E10 was developed. When plating, the positions of the yarn carriers have to be adjusted with high precision. To be able to assess the exact influence of the position of yarn carrier 6 and 7 on the fabric, two modular flexible yarn carriers were developed (Fig. 6).

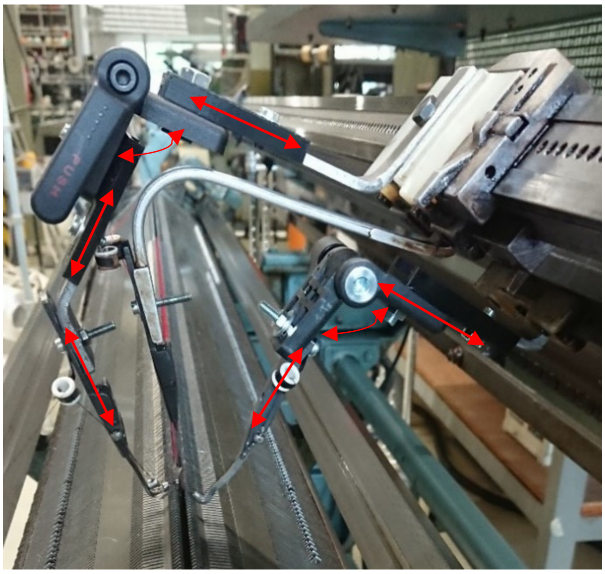

Fig. 6 Attachment of the modular yarn carriers to the knitting machine.

The position can be flexibly adjusted on these yarn carriers. For this purpose, lockable angles and extendable rails were integrated into the yarn carriers. This means that the yarn carriers can be flexibly adjusted on the y-axis (height) and the z-axis (depth). An adjustment on the x-axis (along the needle beds) is not possible.

The positions are determined by their position in relation to three points (Fig. 7):

1. Distance from yarn carrier tip to the carriage plate;
2. distance from yarn carrier tip to the knock-over sinker;
3. distance from yarn carrier tip to the needles.

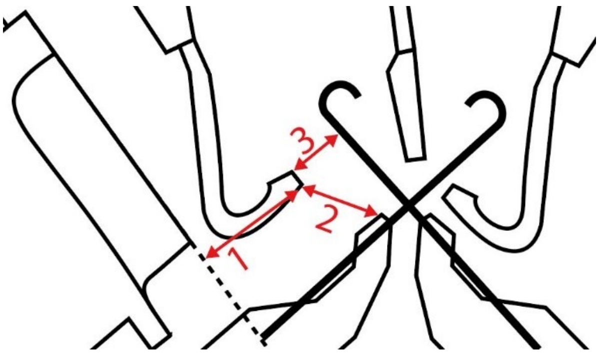

Fig. 7 The three different distances measured to define the exact positions of the yarn carriers.

Moreover, the individual elements of the yarn carrier can be adjusted by means of an infinitely adjustable angle. The position of the yarn carrier can be defined with high precision. The yarn carrier for the front needle bed can be elongated at three points and adjusted by an angle. The yarn carrier for the rear needle bed can be adjusted at two points and an angle (Fig. 6).

The correct position of the yarn carriers is found when:

- the yarn carriers always place the yarns of yarn carriers 6 and 7 (Fig. 1) on the needle latch and push them into the needle hook when sinking;
- the yarns F1 and F2 do not get caught on the plates between the needles;
- there are no defects (such as stripes, dots, holes, …) in the knitted fabric.

Initial trials showed that the yarns F1 and F2 get tangled in the brushes and are not inserted into the needles. Therefore, the experiments are carried out without brushes.

The knitted fabric is building up between the needle beds. This particularly affects the edges of the knitted fabric. If the needles lift, they also lift the knitted fabric or stitch into the already formed knitted fabric and hook into the knitted fabric. This leads to imperfections and even yarn and needle breakage. As mentioned above, this problem could be minimized by increasing the yarn tension, but not solved.

3.1 Test

To find the correct position of the yarn carriers, yarn carrier 6 is brought into three different positions (Fig. 8):

Position 1: The yarn carrier tip of yarn carrier 6 is as close as possible to the needle cross.
Position 2: The yarn carrier tip of yarn carrier 6 is as close and as high as possible to the needles that are to the maximum height.
Position 3: The yarn carrier tip of yarn carrier 6 is as far away from the needles and as low as possible so that the yarn is still placed on the needle latch (Fig. 8).

The standard yarn carrier 8 stays in its standard position. Yarn carrier 7 bed is not knitting. As the knitting is building up between the needle beds, it must be manually tucked down after each carriage stroke. The three positions have the distances reported in *Table* Table 1.

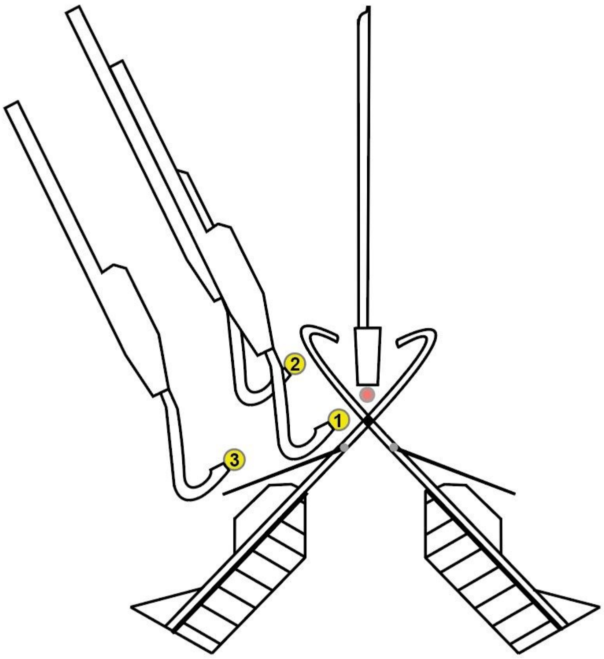

Fig. 8 Yarn carrier 6 is moved into three different positions to find the correct position; adapted from WO2020069856A1.

Table 1. The three positions in which yarn carrier 6 is knitting to determine the most suitable knitting position.

	Position 1	Position 2	Position 3
Distance from yarn carrier tip to the carriage plate (mm)	18.8	17.2	15.8
Distance from yarn carrier tip to the knock-over sinker (mm)	2.1	9.9	12.0
Distance from yarn carrier tip to the needles (mm)	0.1	1.0	1.0

3.2 Results

While knitting in the different positions, videos were taken with a high-speed camera (1,000 frames/s). The recordings were analyzed with regard to the defects that occur. The following causes of defects can be identified from the videos:

- The needle latch is not open far enough so that yarn F1 is guided underneath the latch and the latch cannot grip the yarn.
- The latch pokes into the yarn which is on the needle stem when lowering. When the latch closes, individual filaments of the yarn remain attached to the latch and form a loop again.
- Depending on the carrier position 6 (especially position 3), the yarn gets caught on the knock over sinker. In most cases, the yarn is nevertheless picked up by the needle and forms a new stitch. In some cases, the yarn is gripped by the latch. However, during the lowering of the needle, the yarn slips off of the needle latch before the latch closes.

The three resulting knits (position 1, 2 and 3) are assessed. For this purpose, the number of defects (little holes where yarn F1 has not knitted) is determined. For each test, the defects are counted at five areas in the knitted fabric: left bottom, right bottom, left top, right top and center. In each of the five areas, the defects are counted on an area of 3 cm x 3 cm^2. The three knits have an average size of 25 cm x 45 cm. Table 2 shows the number of defects in the five counted areas.

Table 2. Number of defects in the five specified areas of the fabric knitted with the yarn carrier in position 1, 2 and 3. The number of defects is marked in color: i) 0-9 defects in green, ii) 10-19 defects in orange and iii) ≥ 20 defects in red.

Position 1 (9 cm^2) (1 cm^2)		
25 (2.8)		32 (3.5)
	22 (2.4)	
26 (2.9)		29 (3.2)

Position 2 (9 cm^2) (1 cm^2)		
13 (1.4)		8 (0.9)
	5 (0.6)	
6 (0.7)		11 (1.2)

Position 3 (9 cm^2) (1 cm^2)		
15 (1.7)		22 (2.4)
	20 (2.2)	
34 (3.8)		22 (2.4)

Position 1 has an average of 3 defects per cm^2. Position 2, on the other hand, has a significantly lower defect rate with an average of 1 defect per cm^2. Position 3 is in the middle range with an average of 2.5 defects per cm^2. It can be concluded that position 2 produces results with the lowest defect rate and is therefore the most suitable position.

4 Prototype on circular knitting machine

The yarn carrier prototype was installed on a large circular knitting machine for double face fabrics from Mayer & Cie. GmbH & Co. KG Type FV 2.0. The machine has a gauge of E10, the same gauge as the used flat knitting machine. That makes it possible to insert the same yarns (Di.Vè Waffle 100% polyester filament in three different colors) as in the trials on the flat knitting machine. The machine has 29 feeds and a needle count of 2 x 432 needles.

An experimental set-up was created with magnetic stands as additional yarn feeders F1 and F2 (Fig. 9a). Only one system is active; all other systems are turned off. Yarn feeder 6 inserts the yarn F1 (blue) into the cylinder needles, yarn feeder 7 inserts yarn F2 (yellow) only into the dial needles. These two yarn carriers both create a single face structure in the cylinder and in the dial. A third yarn F3 (red) is inserted through a standard yarn carrier into the dial and cylinder needles, forming a double face structure (Fig. 9b).

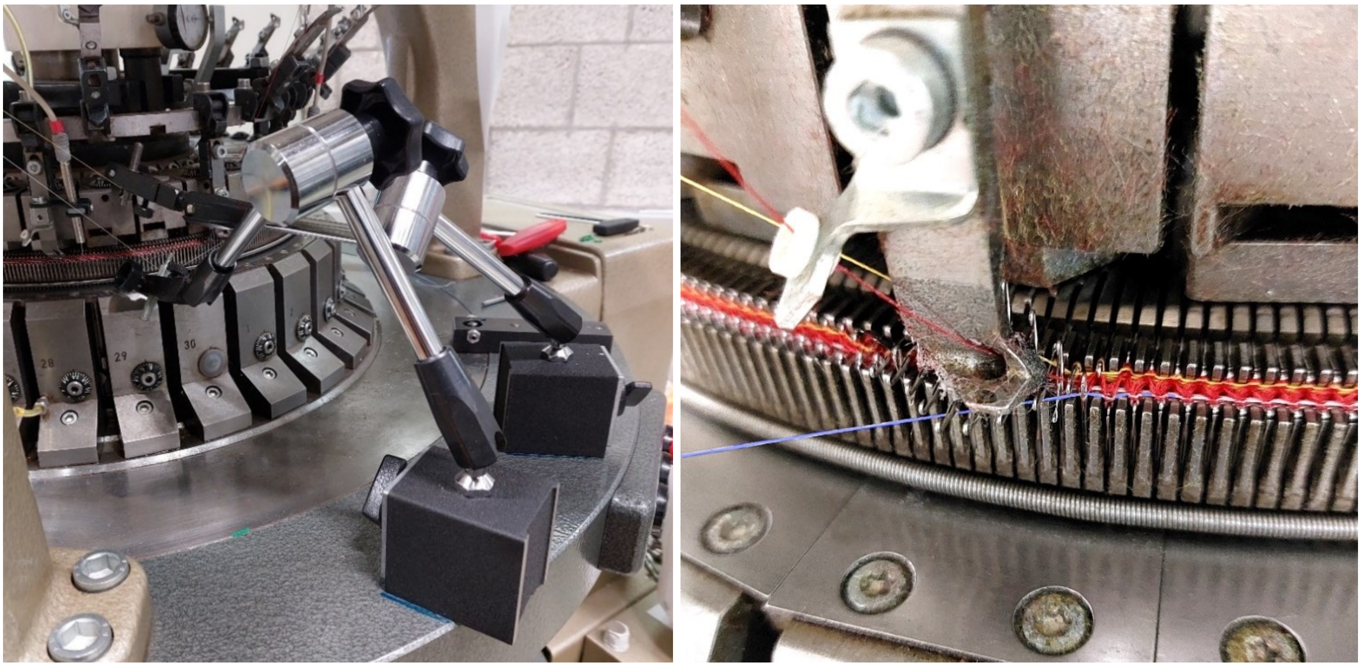

Figure 9 (a) The yarns F1 and F2 were fed to the needles using magnetic stand; (b) a first yarn F1 is inserted in the cylinder needles. A second yarn F2 is inserted behind the dial needles. A third yarn F3 is inserted into the dial and cylinder needles.

Different settings were tested in a series of trials. Compared to flat knitting, in circular knitting the needles move in the cross-direction and the yarn carriers are static. This facilitates the positioning of the yarn carriers.

4.1 Test

All three yarns are supplied to the yarn carriers via yarn feeders. With the help of the magnetic stands, an optimum fixed position for the yarn supply could be found. For this purpose, further developments of a precise feeder to which the position can be precisely determined are currently in progress.

A red polyester yarn is fed as the standard yarn. A blue yarn knits on the cylinder needles, and a yellow yarn knits on the rib needles. Initial trials have shown better results when the tightness factor of the cylinder needles is higher than the one from the dial needles.

4.2 Results

The resulting knitted fabric has no holes or stripes. Although only one feed is active, there is a slight spirality effect. One cause could be that the yarn tension on the double face yarn is rather high and therefore one side of the stitch is smaller than the other side. This results in a new effect, a two-colored stitch: left side red, right side yellow (Fig. 10a). In addition, there are more plating defects on the reverse side of the fabric, which makes the knitted fabric look more irregular.

With higher tightness factor the effect disappears. The plating on the front side of the fabric is faultless. The red yarn completely covers the blue yarn (Fig. 10b). Further trials are conducted on this.

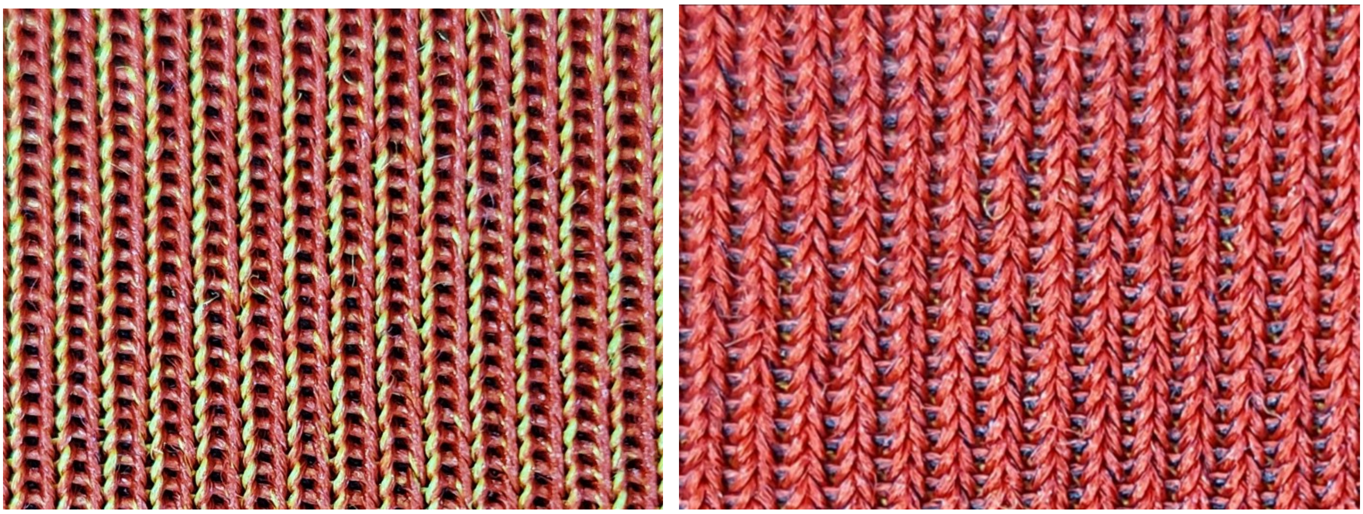

Figure 10 (a) Back side of the innovative knitted fabric. The red yarn is plated only on one side of the stitch so that the yellow yarn is still visible on the other half; (b) front side of the innovative knitted fabric. The red yarn is plated faultlessly so that the blue yarn is barely visible

5 Conclusions and Outlook

The trials on the circular machine were successful and showed promising results while the trials on the flat knitting machine need improvement. Faultless knitted fabrics were produced at industrial speed. These innovative knits are currently being compared with woven fabrics and standard double face knits in order to define potential areas of application.

One the flat knitting machine settings were found that produce improved knitted fabrics. Nevertheless, some further developments are necessary here in order to implement the innovative knitting technology industrially. A device for reliably opening the needle latches has to be installed. A possible solution is offered by magnets or brushes, which are active only on one side of the yarn carrier at a time, so that they do not interfere with the yarn of yarn carriers 6 and 7. Furthermore, the fabric building up between the needle beds could be solved by a stronger fabric take-down and an attachment to push down the fabric.

On the circular knitting machine, innovative plating effects appeared which need further investigations. For this purpose, yarn carriers are in development which can be flexibly adjusted and precisely defined. With the help of these yarn carriers, a series of tests will be carried out in order to assess the exact influence of the positions in combination with the yarn tensions on the plating.

This study shows this new plating needs to precisely control yarn position and tension, this control is more important than with current plating.

Author Contributions

P. Holderied: conceptualization, methodology, validation, formal analysis, investigation, data curation, resources, writing – original draft preparation, writing – review and editing, visualization, project administration; T. Mutschler: conceptualization, methodology, validation, formal analysis, investigation – original draft preparation – review and editing, supervision, funding acquisition; S. Tresp: resources; J. Klausmann: original draft preparation, writing – review and editing; L. Streitenberger: original draft preparation, writing – review and editing; M. O. Weber: conceptualization, methodology, validation, formal analysis, investigation, data curation, resources, writing – original draft preparation, writing – review and editing, supervision, project administration, funding acquisition; M.-A. Bueno: methodology, validation, formal analysis, investigation – original draft review and editing, supervision. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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