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INDUSTRIE 4.0 – Automation in weft knitting technology

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Abstract. Industry 4.0 applies to the knitting industry. Regarding the knitting process retrofitting activities are executed mostly manually by an operator on the basis on the operator´s experience. In doing so, the knitted fabric is not necessarily produced in the most efficient way regarding process speed and fabric quality aspects. The knitting division at ITA is concentrating on project activities regarding automation and Industry 4.0. ITA is working on analysing the correspondences of the knitting process parameters and their influence on the fabric quality. By using e.g. the augmented reality technology, the operator will be supported when setting up the knitting machine in case of product or pattern change – or in case of an intervention when production errors occur. Furthermore, the RFID-Technology offers great possibilities to ensure information flow between sub-processes of the fragmented textile process chain. ITA is using RFID-chips to save yarn production information and connect the information to the fabric producing machine control. In addition, ITA is currently working on integrating image processing systems into the large circular knitting machine in order to ensure online-quality measurement of the knitted fabrics. This will lead to a self-optimizing and self-learning knitting machine.

1. Introduction

The requirements for the manufacturing companies are very complex. Industry requires short response time and more efficient systems in order to remain internationally competitive. Due to the increasing number of product variants and small lot sizes the development of fast and high flexible production systems is essential, especially to small and medium-sized German enterprises. The Industry 4.0 approach can support industrial production in order to fulfil the market´s requirements [1, 2].
By technical inventions such as the Spinning Jenny and the mechanical loom, combined with the increasing availability of water and steam power, the first industrial revolution evolved facing the textile industry at the end of the 18th century. The second industrial revolution was launched at the beginning of the 20th century and was mainly caused by the mass production of goods (e.g. by Fordism). This flow production was realized by the access to electrical energy. At the beginning of the 1970s the 3rd Industrial Revolution started. This period was marked by the automation or computerization, the use of robots, new materials and of centralised control systems. The term "Industry 4.0" expresses that the industry is on the threshold of the 4th industrial revolution. Figure 1 shows the development of the industrialization [3, 4, 5].

The German location as a high-wage production region needs to stay competitive. Therefore new solutions and methods for flexible and decentralized production and control systems are to be developed. The aim of the production technology in Germany is to offer individualized products to mass production rates with a minimum planning effort. The development in the field of production technology is extremely important for Germany to remain globally competitive. In recent years, many companies moved their production abroad in order to save manufacturing costs. The next steps of development in automation will be the integration of so-called cyber physical production systems (CPPS) using the so-called Internet of Things. The merging of real (physical) objects with information processing (virtual) objects is called cyber-physical system (CPS) .These systems will offer a cross-linking of resources, information, objects and people in order to achieve efficient and high flexible manufacturing. The cross-linking results in real-time managing and optimizing the entire production system, future companies as well as the entire logistic supply networks [6, 7].

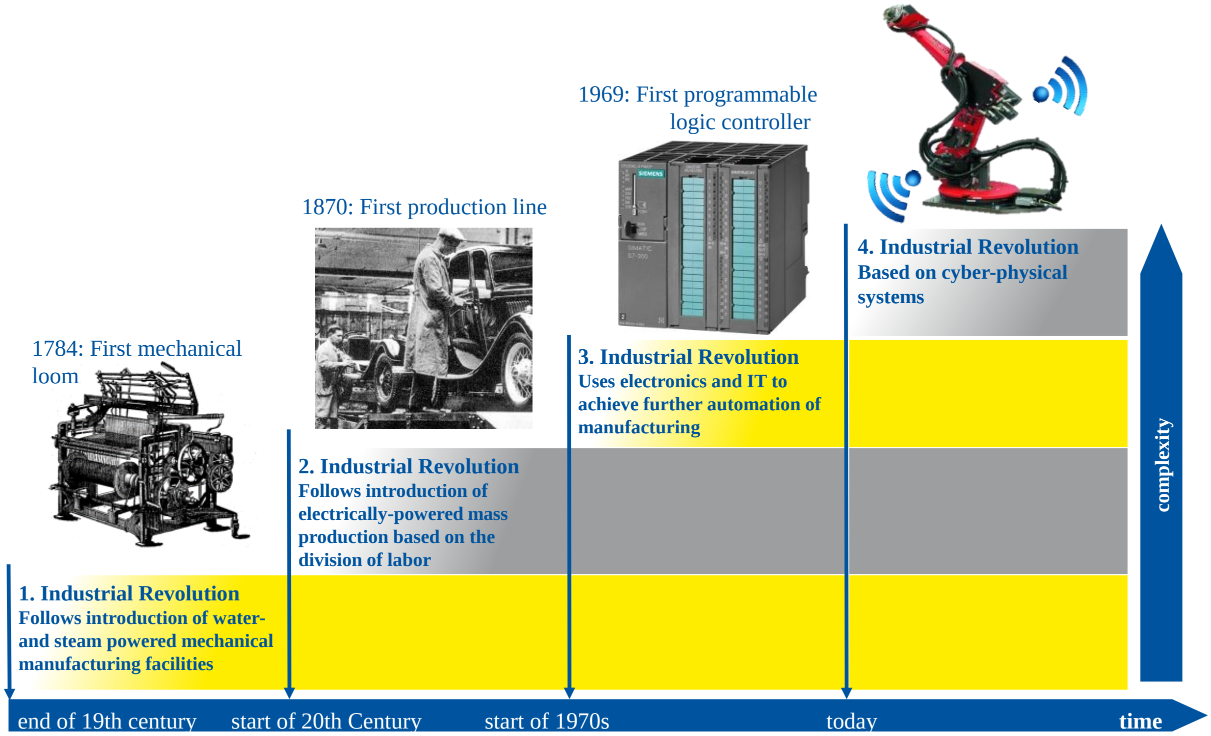


Figure 1. Development of the 4th revolution in industry [8, 9].

2. Why should the Industrie 4.0 approach be applied to the textile industry?

A survey carried out by Fraunhofer-Institut für Arbeitswirtschaft und Organisation (IAO) in 2013 show that 98,6 % of the respondents of German textile machinery manufacturers and fabric producers announced that flexibility in production will be one of the parameter of maximum significance for their future success. Flexibility means a high adjustability to unforeseen circumstances. Moreover 62 % of the respondents declare that reacting to short-term control and coordination of production orders means a high to very high effort to the companies. Especially for the apparel industry short product lifecycles, great fluctuations in demand as well as great tendencies of the customers regarding individuality require high flexibility and high efficiency in manufacturing [10, 11].

The textile production has been mainly outsourced to South-East Asia and the competitive pressure of the established German textile companies is increasing. While in 1970 there have been about 896,911 employees in the German textile industry nowadays the numbers of employees in Germany decreased to about 79,290 [12]. Challenges of industrial actors in implementing Industrie 4.0 applications are perceived regarding standardized processes, the protection of company owned knowledge as well as the skills shortage in textile [13, 14, 15]. The cross-linking of diverse individual process steps of the entire textile process chain to an overall automated process is definitely relevant for the textile industry. Because of this relevance Industrie 4.0 regarding the entire textile process chain, including the knitting process, is a big development and research topic in Germany. At the Institut für Textiltechnik der RWTH Aachen University, Aachen (ITA) the automation of the knitting process regarding Industry 4.0 applications is a big research topic. The researchers´ aim at ITA is to lower the entrance barriers for the German knitting machine manufacturers as well as the German fabric producers regarding Industry 4.0. ITA is collaborating with the Deutschen Institute für Textil- und Faserforschung Denkendorf – Zentrum für Management Research (DITF-MR), Denkendorf regarding Industry 4.0 and knitting technology. The DITF-MR for example are analysing the potential of Industry 4.0 regarding the weft knitting technology by a survey called “Strick 4.0 in Baden-Württemberg”. The demand of innovation of the knitting industrial sector will be analysed in collaboration with industrial partners of the Baden-Württemberg region [16,17].

3. Project example: SpeedFactory – Automation for the sports industry

The research project SpeedFactory is publicly funded by the national program “Autonomik für die Industry 4.0”. This program contributes to the implementation of the High-Tech Strategy 2020 of the Federal Republic of Germany. The program focuses on a new era of production through networking of modern information and communication technology (I & C technologies) and industrial production. At the same time versatile impetus for the creation of new innovative products, services and business models can be created using new production technologies. The project has started in October 2013 and will end after a three - year period in 2016. Each partner will provide its individual know-how in their respective fields of work to the project plan. The consortium consists of the following partners, who contribute both in industry and research: Johnson Controls GmbH, Burscheid - a leading automotive supplier. The project team of the adidas Group, Herzogenaurach consisting of experts from the adidas Innovation, Global IT innovation and sourcing. Pfaff KSL Keilmann Sondermaschinen GmbH, Lorsch – Experts in manufacturing of individual robot production plants belong to the consortium as well. In addition, the fortiss GmbH, Munich is part of the consortium.

The aim of this project is to encourage the development of autonomous systems. Germany needs to expand its leading position as an industrial centre for new and pioneering internet-based technologies. The research covers topics such as production logistics, basic cognitive technologies, human-computer interaction (HCI) and 3D in industrial applications. The project’s objective will be reached by creating solutions for the automatic production and handling of limp fabrics. Therefore robot and handling systems will be deployed and developed. Within the research project, the ITA is focusing on the entire textile process chain, especially on the textile fabric manufacturing, the handling as well as on the joining process [18, 19].

4. Cross-linking of the knitting process with upstream process steps – Smart bobbin [13]

By the use of these tracking and tracing systems fabric producers as well as consumers are able to follow the products history. Therefore, the following data are to be transferred during the production process [20]:

- Where is the product stored, how much material is left?
- Which production steps have been worked out already?
- In which condition is the product at the moment?

In order to save and transfer information the use of optical codes with an estimated ratio of 75 % is widely spread. Because of decreasing prices, the small size and the increasing performance the ratio of applications for the Radio-Frequency Identification (RFID) Technology is increasing as well [21-24].

The RFID Technology offers high potential regarding Industry 4.0 applications. By the use of RFID process and/or product data can be transferred from e. g. machine to machine. Research at ITA show that yarn quality during the spinning process can be detected using spinning machine embedded sensors. The information of the location of errors along the yarn length is saved on a RFID chip which is placed into the corresponding bobbin. By the use of the RFID chip and the corresponding receiving device these error data will be transferred to the fabric producing machine – knitting or weaving machines. Investigations at ITA show that as soon as the smart bobbin (weft bobbin) is located at the weaving machine the data can be transferred to the machine’s Soft PLC in order to control online the

production speed depending on the yarn quality characteristics (errors). The development of this concept has been honored by the Wilhelm-Lorch-Stiftung in 2014 [25, 26].
ITA is currently working on transferring the concept to the large circular knitting technology in order to recognize the characteristics of each bobbin characteristics in the bobbin creel (yarn material and fineness, color and yarn length, yarn tension) (see Figure 2). The online recognition of the diverse yarn characteristics in the creel related to the knitting system positioning will be especially relevant for the jacquard knitting technology. ITA is expecting to reduce the setting time after changing yarn material in the bobbin creel by about 20 %. In case of knitted product changes the operator is able to react more flexible to the pattern and/or yarn changes because the operator is no longer forced to collect the information manually. In times of the demographic change and a rising lack of educated operators systems of data transformation help to increase the international competitiveness of the German knitting industry.

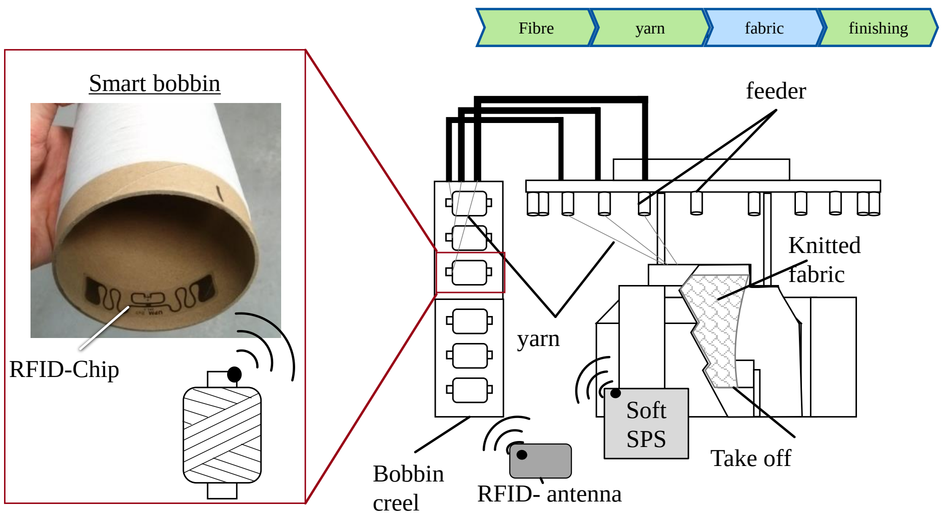


Figure 2. Smart bobbin – concept of RFID-technology used in large circular knitting technology [27].

Besides the smart bobbin research at ITA, there have been investigations in physically knitting QR-Codes in order to transfer fabrics' information. By this technology the knitted fabric can be provided with product, downstream or upstream process information. In this case no additional chip or code is to be purchased including the risk of getting lost or being damaged in downstream process steps. The readability and sizes of the QR-Code directly corresponds on the one hand with the amount of the machines' needles (machine gauge) and the yarn material and fineness. On the other hand the interaction of the knitting process parameters speed, take-off tension and sinker height influences the codes' dimension and therefore the readability of the code.

5. Assistance systems - Augmented Reality (AR) in knitting

ITA is also working in including the operator into the field of Industry 4.0. The development of human-machine interfaces (HMI) such as Augmented Reality (AR) based assistance systems supports the operator. The setting of the process parameters according to the used material and desired product specification are worked out by operators according to the gained experience and knowledge. Especially in times of demographic change and staff shortage for machine operators in Germany it is increasingly important to systematize this individual process knowledge in order to support inexperienced employees. These assistance systems can be used on the one hand for the logistic purpose and in production, and on the other hand as assistance in maintenance operations [28].

6. Image processing in knitting

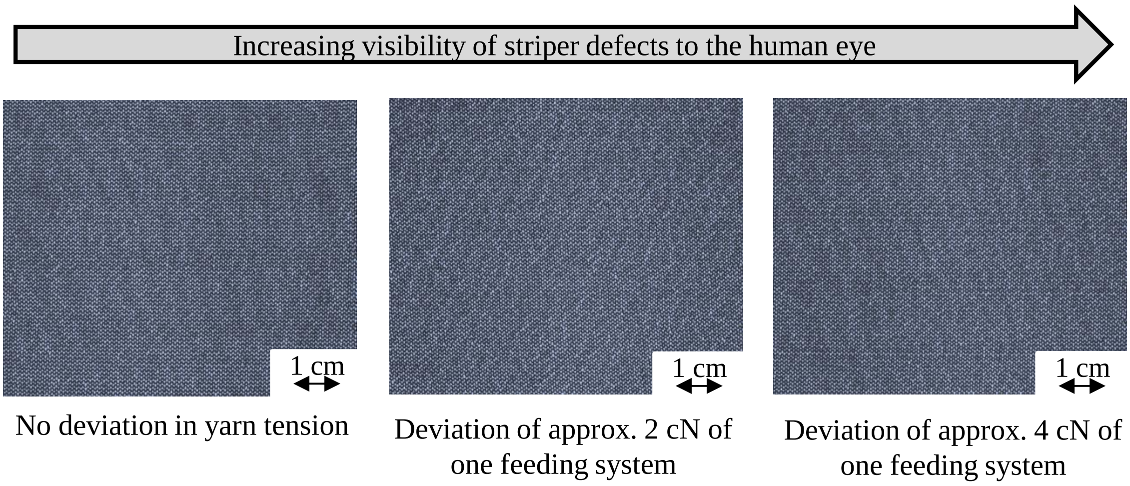
Optical characteristics, such as the loop uniformity and surface condition, are crucial quality criteria of knitted fabrics. The human eye can detect deviations of less than 20 µm. In the field of technical textiles (e.g. flame resistant underwear, fencing suits, skiing underwear) and fine knit-wear (e.g. socks) single, selective defects in the fabric can lead to fabric rejections. A fabric defect is any abnormality in the fabric that hinders its acceptability by the consumer. Defects are caused either by inhomogeneous yarn material mixture, fineness and tension or by false setting of knitting process parameters such as speed [rpm], sinker height [mm], yarn tension [cN], take-off tension [N] or the width of the spreader [mm].

In particular, undetected defects with spatial extent in the production direction (e.g. color defects, pattern error, laddering) are critical because of the impact on in some cases the entire production batch. Moreover, repeating errors in the fabric texture, such as striper defects or loop distortion are hardly to be differentiated from an intended pattern texture. These defects just can be detected during production by trained and experienced operators. Such visual inspection tasks are perceived as monotonous and tiring to the operators [29]. Moreover, the operators in large circular knitting manufacturing companies supervise several machines at the same time, so the operators cannot guarantee a 100 % quality observation. Therefore, the manually inspection should be substituted by image processing systems. The digital image processing allows outsourcing the visual inspection by computer technology. In this way, complex and repetitive tasks of error detection, such as counting, measuring and defect detection, are solved by computer systems. Although in other technologies, like the steel or automotive industry, visual detecting systems are common because of the practical advantages, there has been minimal application of image-processing systems in the knitting industry, yet.

ITA is collaborating with the Institute of Imaging and Computer Vision of the RWTH Aachen University investigating the possibilities in automated detection of defects in knitted fabrics. Striper defects for example appear in case the tension of at least one yarn along the knitting cylinder differs from the others. Small differences in yarn tensions are hardly to be detected by the human eye during production, but do affect the fabric quality. The fabric´s treatment during the finishing process – especially during the dyeing process – leads to an increasing visibility of the striper defects. As a result, the fabrics are to be declared as substandard goods or rejects (Figure 3).

Nowadays, some defects, such as stripers resulting from little differences in yarn tension, are difficult to detect visually and during production even by knitting experts. As a result of the collaboration with the Institute of Imaging and Computer Vision of the RWTH Aachen University, an image processing method has been developed allowing to significantly enhancing stripers in knitted fabrics. Images are first pre-filtered to increase contrast and homogeneity. Subsequently, spectral filters and correlation applications are applied to enhance visibility of the stripers. The resulting images can be displayed on-screen to improve the reliability of manual inspection or processed further in order to allow training of an automated, machine learning-based classifier. Once trained, the classifier is able to detect stripers in new images with high reliability and without any human interaction.

In the current downstream fabric inspection the open-width fabric is examined optically. Error avoidance during the knitting process is not possible with the current downstream fabric inspection. Fabric areas with failures are recognized and rejected after the downstream fabric inspection. The retrofit operation in knitting plants includes not only the yarn change (approx. 30 minutes), the pattern change (0.5 days with mechanical equipment , for 1 hour at jacquards) in addition to patterning and material-dependent adjustment process of the knitting parameters (up to 1 day).



Machine:
Large circular knitting machine, BSM 3.0, Beck GmbH, Albstadt (E24, 30“), 18 systems activated, sinker 0.5, Speed 30 rpm
Material:
Polyester yarn, 68 filaments, 293 dtex, texturised, high intermingled

Figure 3. Increasing in striper defect visibility by deviated yarn tension of one of 18 feeding systems

In addition to defect detection, image processing systems can also support the prototype development of new knitted products. Although program software tools such as the M1 software of the company H. Stoll AG & Co. KG, Reutlingen is able to visualize digitally the different pattern modules, the calculation of the resulting dimension of two or more pattern combinations is not possible in industry yet. Therefore, the prototype development of knitted products is worked out by trial and error. This development process can take up to a year depending on the pattern complexity of the product. Investigations at ITA show that the mesh density of a pattern is depending on the surrounding pattern (Figure 4). This influence can either be simulated ex ante or visually measured online using a camera system, image processing and a self-learning algorithm. The knitted resulting dimensions of the single pattern regions are measured online and compared to the target dimension. The self-learning system will enable to change the knitting program in terms of adding or reducing the amount of loops per pattern region. Finally the cross-linking to the machine control will ensure the production adjusted knitting program [30]. A target-actual comparison provides the measurable deviation from the desired structure so that the necessary adjustments can be performed.

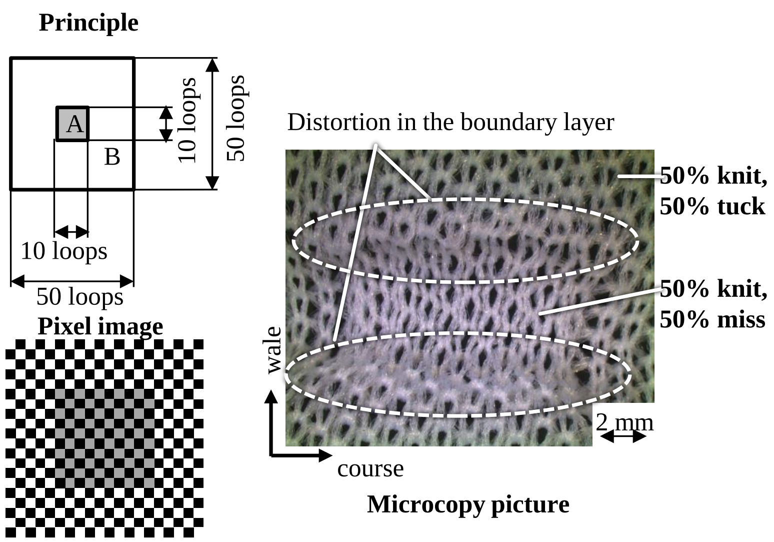
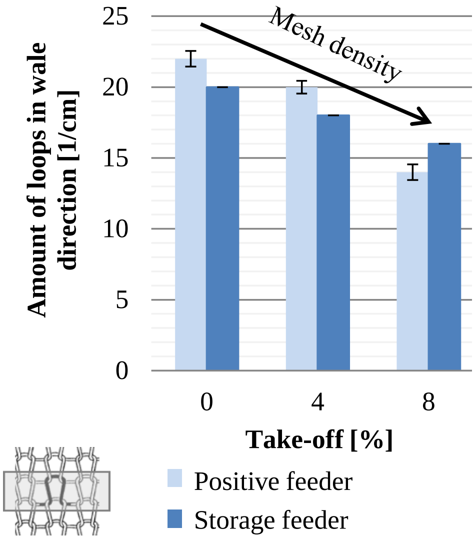
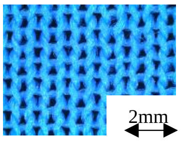
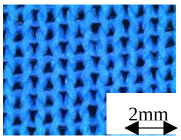
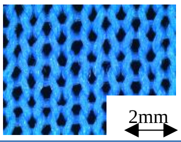


Figure 4. Exemplary distortion of the inner pattern region by the surrounding of another pattern region

7. Online and reproducible control of the spreader width in large circular knitting machines

In the large circular knitting technology the knitted tube is formed by a so-called spreader to a double-surfaced knitted fabric. As a result, this double-surfaced knitted fabric is guided to the middle of two take-off rolls and is either wound to a cloth bale or folded into a cloth box. The adjustment of the dimensions of the spreader affects significantly the properties of the knitted fabric in terms of loop size and loop distortion. Additionally investigations at ITA show that the take-off tension among other process parameters significantly influences the mesh density in wale direction (Figure 5). Currently, the spreader width is manually adjusted according to the knitting patterns and to the yarn elasticity. This adjustment is based on the experience and knowledge of the operator in charge. Moreover, due to the spreader design, there is no possibility to adjust the spreader width in a reproducible way. Two bars are literally to be pulled apart from each other by the operator. Therefore, the width optimum according to the selected material and pattern is not known. Furthermore, even if the optimum is reached by accident, the reproducibility of the corresponding setting parameters is not given. The concept at ITA is to measure the fabrics pressure to the spreader bars by pressure sensors. The pressure of the fabric directly corresponds with the fabric characteristics regarding elasticity, tensile strength and mesh density. Figure 6 shows the results of a drape-test of five different knitting patterns in collaboration with the Faserinstitut Bremen e. V., Bremen, Germany. The diagram shows that the fabric resistance is depending on the combination of the three existing pattern or cam elements in large circular knitting: miss, tuck and miss.



Take-off setting [%]	Microscopic pictures	Mesh density [1 / cm²]
0	 2mm	148
4	 2mm	146
8	 2mm	124

Machine:
Large circular knitting machine, BSJM 1.3, Beck GmbH, Albstadt (E16, 19“), 4 systems activated, sinker 0.3, Speed 28 rpm
Material:
Polyester yarn, 68 filaments, 250 dtex, texturised, high intermingled, Single Jersey

Figure 5. Influence of the take-off settings on the mesh density in single jersey fabrics.

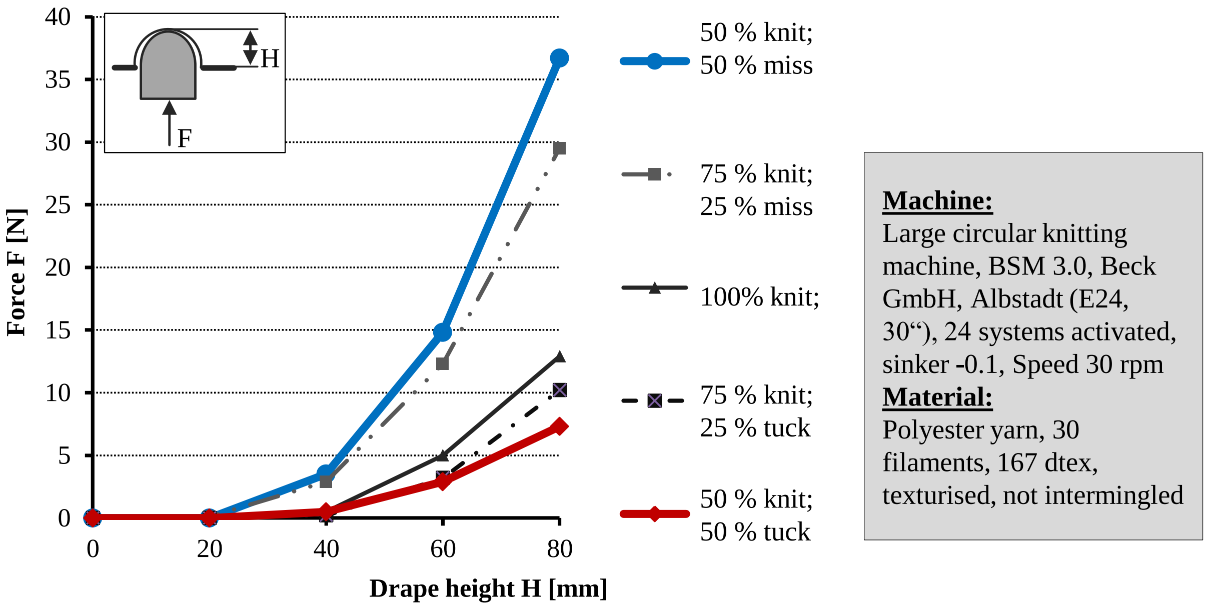


Figure 6. Drape-test results of different combination of cam elements – in collaboration with Faserinstitut Bremen e. V., Bremen.

In addition to the varying resistance the circumference length of the circular knitted tube also differ by the chosen pattern. The combination of cam elements results in varying mesh densities in wale and course direction. According to that the porosity of patterns also varies the resulting pressure of the fabric to the spreader. That is the reason why the spreader of the circular knitting machine is to be adjusted according to the desired product. The reproducibility of fabrics' quality by adjusting the spreader settings gets more complicated when lots of pattern changes are introduced by using the electronic jacquard technology. The variation in pressure of the fabric can be controlled by the new spreader control concept. As a result ITA ensures the online and product specific, reproducible settings of the spreader width, even for jacquard knits. In order to ensure the acceptance by fabric and knitting machine manufacturers the price is aspired being under 1000 € per system (development status).

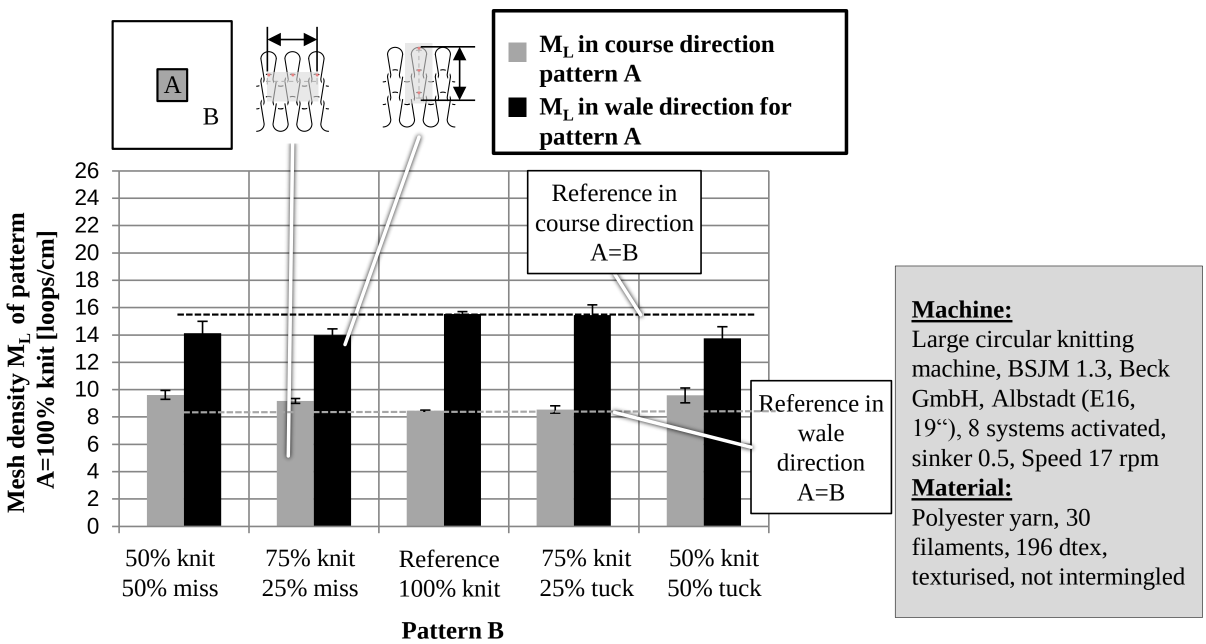


Figure 7: Variation in mesh density according to selected combination of two patterns

8. Summary

The Industry 4.0 and automation approach is relevant to ensure the international competitiveness of the German knitting industry because of the demographic change and experience-based knowledge in production. Currently, the correspondence data of the knitting process parameters are rarely systemized in industry. The collecting and systemization of process data is a basis requirement for automation and intelligent production. Aim of this intelligent production using self-learning and self-optimizing systems in knitting is to increase product quality, decrease fabric rejection costs and support the operator during manufacturing.

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