Classic or fully automated technology lines?

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Abstract. In this paper we compared a classic technological lines and a fully automated line for the manufacturing of 100% cotton yarns. For this comparison we analyzed the complexity of classical and fully automated technological lines, the differences between the yarn structures, aspects related to the quality of textile yarns but also an analysis of production costs and benefits. The spinning mill is the first sector in the textile field, the sector in which the textile yarns are made. The quality of textile products, fabrics, knits, garments or technical articles are strictly dependent of the quality of textile yarns. The yarns are made of short fibres of cotton, wool, linen, hemp or other raw materials, with a great unevenness of the physical-mechanical characteristics, and the technological engineer must make a series of adjustments, settings of the machines so that the yarns made have a lower unevenness. This is the reason why the technological engineer must set the technological process so that the yarns are of adequate quality, have low production costs and deliver orders to the beneficiaries within the terms established by the commercial contracts concluded with them. In order to decrease the production costs, there were permanent concerns for the introduction of new automation elements, so that in the field of cotton spinning reached an extremely high level, right at the fully automated cotton spinning mill. Practical, on the technological line there are only two operators, one that supplies the technological line and one that transfers pallets with bobbins from the palletizing robot to the transport means. Practically the technological lines are composed of the same machines, but the automation elements on each machine and the aggregation systems between machines allow the almost complete elimination of the operators for service of machines. Given the complexity of the technological lines and the difference between the human resources for the two technological lines, in the first step we made a comparative calculation of the costs for the salaries of the operators and the taxes that an employer must pay. Then we made a comparative calculation of energy consumption. The comparative analysis was done for a cotton spinning mill with a production of 4000 t/year, classical yarn, 100% cotton yarn, with average fineness Nm40, made on ring spinning machines. Finally, we made a comparative study of the investment effort and the amortization of the investments made, amortizations which is reflected in the total costs and then in the delivery price of the yarns to the beneficiaries.

1. Introduction

Industrial automation has evolved in the last decennium as a propulsive power in all production systems and exert an extensive function in industrial and manufacturing area. [1]
Thus, in most area of textile manufacturing, automation represent a leading key to quality enhancement and competitive costs. There are several reasons that sustain the benefits of automation in the textile industry. Some of the major assets achieved through automation include: augmented production at lower cost, enhanced quality, minimized energy consumption, reduced environmental impact, removal of human error, easy identification of faults and improved customer satisfaction. [2]

The processing of cotton and cotton-type fibers requires the following conditions: proper choice of raw materials according to the destination of textile products; optimization of the technological parameters for all equipment comprised in the technological flow; continuous control of the processing process.

Increasing demands for the characteristics and quality of textile products imposes changes in technology and equipment construction, which have led to increased labour productivity and economic efficiency.

The main achievements of the automation of the cotton spinning technological lines are:
- **in the blowroom unit**: automatic feeding with fibrous materials directly from bales (MBG - E 6044, Optomix, Rotomix, MO and Flemix Hergeth Hollingsworth, Unifloc Rieter, B12 Marzoli, Blendomat BDT013, BDT019 and BDT020 Trützschler), imposed on economic reasons, and on the other hand on the basis to achieve the most uniform possible blends; aggregation of blowroom with cards by connecting them with pneumatic and automatic transport systems, operating in synchronized with cards (Exactafeed FBK 533 Trützschler, Aerofeed Rieter, Masterchute Hergeth Hollingsworth, CF Crosrol, B 138 Marzoli); [3-8]
- **for cards**: automatic change of full cans after deposition of a definite length of sliver (KHC - Trützschler, CBA 3 and CBF - R - Rieter); automatic transport of full cans (Canny - one Trützschler); use of self-regulating systems in long-term (UCC - L Uster, Correctacard CCD Trützschler) and in short-term (UCC - S Uster, Correctafeed CFD and ICFD Trützschler, Masterleveler Hollingsworth, ST - Marzoli); [4-9]
- **for draw frames**: using regulation systems on short-term, medium-term and long-term of fineness of the obtained sliver (RSB 951 Rieter, servo draft connected to the Draftcommander control system and Sliver kit Trützschler computer system, HDC Howa, DYH 500 and DYH 800 Toyota, cherry DX 500 Hara, SV 810 ASC Alfamatex, 1548 Chemnitzer, SH 1E, SH 2 E and SH 802 E-Vouk, servo draft Zinsen); aggregation of the draw frame passage I with the draw frame passage II and III through a closed circuit of cans (Canlink Rieter via the “Pinnen” system); Automatic full cans changing devices at pre-set tape length setting (SV 810 ASC Alfamatex); aggregation of last draw frame passage with unconventional OE Rotor spinning machine (servo Rieter); [5-7, 9-11]
- **at roving frames**: stop of winding of the roving when a fixed length is settled; pneumatic insertion of the roving into the work arm (Chemnitzer); generalization of automatic doffer (Toyota, 25 s/6 bobbins, Howa, 3.5 min/doffer, LABX Marzoli, 766 Rovematic Hollingsworth); aggregating with ring spinning machines (Grossenhain, Tac and Tab Electro-Jet); [5, 7, 9-12]

Werner Klein The Rieter manual of spinning, ebook, vol. 3, Spinning preparation, Schwabe AG, 2018
- **for ring spinning machines**: automatic doffer with a range of specialized systems: SCD (Stationary Cop Doffer), Robo-doff, CO-WE-MAT Laser; direct transportation to the winding machine by means of a transport system (Servo - disc); aggregation with the roving frame (SMA- Spinning Mill Automation - Toyota) or/and with the winding machine (Robo-load); automatic feeding of the bobbins from the grid; automatic stop of feeding of spinning unit at yarn break (Roving - Guard). [5, 10-13]

2. Analysis of technological flows
As specified in the introduction, aim of this work consist in a comparison between the classic flow, a carded system, and an automated flow. The technological line for the classic flow is represented in figure 1.
Figure 1. Classic technological flow (line).

Used abbreviations: B – blow rooms; C – cards; DF I – draw frames, the first passage; DF II – draw frames, the second passage; RF – roving frames; RSF – ring spinning frames; WM – winding machines.

The intermediate products produced on this technological flow (bobbin with roving, cop and bobbin with yarn) are shown in figure 2.

Figure 2. Classic technological line. Intermediate products and finished product.

From the point of view of manufacturing technology, the classical technology line is quite expensive due to several semi-finished products, which lead to more disruption of the technological flow. Thus, a quality control at several points, between operations, after several machines is needed. So automation of the technological line would be beneficial, but an analysis of this costs have to be also performed.

3. Analysis of the yarn structure and destination

Figure 3 represents the structure of the classic yarn produced on both a conventional and an automated line. Differences may occur due to the intervention of robots for breaking elimination in the ring-spinning frame. [14]

Yarn faults arising from the breaking elimination in the case of operator interventions may be assigned to lower classes of defects (faults).

Through adjustments on the winding machines these faults can be removed, but instead others of the higher classes appear.

Figure 3. Structure of classic yarn. [5]

In the structure of the classic yarn, the fibers have a random position. Besides, the number of fibers in the cross-section and their radial positions is also variable. Moreover, for a mathematical analysis, we can approximate that fibers describe helical trajectories, after a right cylindrical screw.

Taking into consideration the fiber arrange in the yarn structure, it is obvious that most fibers contribute with their own breaking load to the yarn breaking load.

The presence of short fibers, with different lengths in the area of 10-40 mm, with a rather large non-uniformity of the length of the fibers, exert an influence upon the irregularity of the yarn fineness. Thus, this fineness irregularity generates irregularity of the burst load along the yarn. [15]

4. Analysis / Evaluation of production costs

For the evaluation of production costs, two technological lines, classical and fully automated and aggregated, were taken into consideration. These lines, designed for 100% cotton fibers processing, produce yarns with average fineness Tt=25 tex (Nm 40) and a total production of 4000 tons/year. The assortment range of yarns is as presented in table 1.
Our proposal concerning the automation of the classical technological line refers to 12 automation elements, namely: automatic cans change at cards; carousel for the transportation cans between cards and draw frame first passage; automatic cans change at draw frame 1; carousel for the transportation of cans between draw frame first passage and draw frame second passage; automatic cans change at draw frame second passage; carousel for cans transportation between draw frames and roving frames; automatic doffer at the roving frame; carousel transportation of roving bobbins towards ring spinning machines; robots for repair ends down at the ring spinning machines; automatic doffer at ring spinning machines; carousel transportation of cops towards winding machines; equipment for the packaging bobbins yarn boxes.

| Yarn number | Fineness [Nm] | Destination | Weight in production [%] |
|-------------|---------------|-------------|--------------------------|
| 1           | 34            | Weft        | 44                       |
| 2           | 40            | Weft        | 30                       |
| 3           | 50            | Warp        | 26                       |

For the comparative analysis of production costs we took into consideration only:

a. raw material costs;

b. costs due to human resource, wages and social tasks;

c. costs caused by energy consumption;

d. amortization costs as a consequence of the investment effort.

Preceding the evaluation, the parameters of the preliminary spinning plan were calculated aiming to establish the kinematic and technological parameters required to obtain yarns with a quality according to the standards. Additional, at the end of the preliminary spinning plan, the calculation part envisages the theoretical production for all equipment contained in the technological flow along with the performance of the machines and the practical production. By means of the technological losses, the necessary of semi-finished products was determined for each technological phase, followed by calculus of machine number in order to establish a correlation of production capacities, table 2.

All these are components of the final spinning plan that furnish us information about the quantities of raw materials and semi-finished products and the number of machines for each technological phase.

| Technological phase               | Number of machines |
|-----------------------------------|--------------------|
| Blowroom                          | 1                  |
| Cards                             | 23                 |
| Draw frames, I and II             | 5+5                |
| Roving frames                     | 11                 |
| Ring spinning machines            | 55                 |
| Winding machines                  | 6                  |

4.1. Raw material costs;

Taking into account the technological losses, the value calculated for the yield of raw materials utilization for both classical and automated technological flow, are 95.3% and 95.1%, respectively.

Technological lines work 254 days/year, 24 hours/day, 3 shifts of 8 hours. From the calculations of the final spinning plans result a requirement of 700.26 kg/h raw material for the classic technology and 703.24 kg/h for the automatic line. Considering the price of cotton fibres, 1.6 USD/kg, \[16\], and the exchange rate 4.4 RON/USD, costs for raw material are 30.052 mil RON / year and respectively 30.180 mil RON / year for the classic and automated technological flows.
4.2. Costs due to human resource, wages and social tasks:
For this evaluation, the calculation of the needed human resource was performed according to the number of machines and their service standards.

The number of employees for each technological phase, men (M), and women (W), required for the three production shifts is specified in table 3, for classic technology, and table 4, for the automated technology. These values include also personnel reserves for medical leave situation and holiday.

| Profession name                  | Shift I W | Shift I M | Shift II W | Shift II M | Shift III W | Shift III M | Total W | Total M | Reserve Total |
|---------------------------------|-----------|-----------|------------|------------|-------------|------------|---------|---------|---------------|
| Blow room                       | 1         | 7         | -          | 4          | -           | 4          | 16      | 1       | 17            |
| Cards                           | 6         | 6         | 6          | 2          | 6           | 2          | 28      | 1       | 29            |
| Draw frames I and II            | 10        | 10        | 10         | 1          | 1           | 1          | 31      | 1       | 32            |
| Roving frame                    | 10        | 10        | 1          | 10         | 1           | 10         | 33      | 1       | 34            |
| Ring spinning machines          | 33        | 4         | 33         | 3          | 33          | 3          | 109     | 7       | 116           |
| Winding                         | 2         | 1         | 2          | 1          | 1           | 9          |         |         | 9             |
| Quality control                 | 4         | -         | 4          | -          | 4           | -          | 12      | 2       | 14            |
| Warehouse raw materials         | 1         | 1         | -          | -          | -           | 2          | 2       | -         | 2             |
| Yarn deposit                    | 1         | 4         | 1          | 2          | 1           | 2          | 11      | -       | 11            |
| Diverse personnel               | 2         | 17        | 2          | 15         | 2           | 15         | 53      | -       | 53            |
| **Total staff**                 | 70        | 42        | 68         | 28         | 28          | 28         | 304     | 11      | 315           |

| Profession name                  | Shift I W | Shift I M | Shift II W | Shift II M | Shift III W | Shift III M | Total W | Total M | Reserve Total |
|---------------------------------|-----------|-----------|------------|------------|-------------|------------|---------|---------|---------------|
| Blow room                       | -         | 4         | -          | 2          | -           | 2          | 8       | -       | 8             |
| Cards                           | 6         | 6         | 6          | 2          | 6           | 2          | 28      | 1       | 29            |
| Draw frames and roving frames   | 2         | 1         | 2          | 1          | 2           | 1          | 9       | -       | 9             |
| Ring spinning machines          | 11        | 1         | 11         | 1          | 11          | 1          | 36      | 3       | 39            |
| Winding                         | 2         | 1         | 2          | 1          | 2           | 1          | 9       | -       | 9             |
| Quality control                 | 4         | -         | 4          | -          | 4           | -          | 12      | -       | 12            |
| Warehouse raw materials         | 1         | -         | -          | -          | -           | -          | 1       | -       | 1             |
| Yarn deposit                    | -         | -         | -          | -          | -           | -          | -       | -       | -             |
| Diverse personnel               | 2         | 13        | 2          | 13         | 2           | 13         | 45      | -       | 45            |
| **Total staff**                 | 28        | 26        | 27         | 20         | 28          | 20         | 148     | 4       | 152           |

There are differences in the number of workers, the classic approach requires 315 workers whilst the automated one needs only 152 workers, less with 163 workers compared to the classic line.

Generally, in Romania, the basic salary of workers in the textile industry has the lowest value in the economy compared to other industries.

According to HG 935/2019 [17], the minimum gross salary from 1st January 2020 is 2230 RON/month. As a result of the pressure exert by the trade unions and the very low unemployment rate, less than 2%, wages have been increased. To these wage costs are added also costs with social contribution allowances. Therefore, for the companies this implies a minimum labor cost of 3280 RON/month for each worker.

This amount includes, therefore, both staff remuneration and social burdens supported by the employee and the enterprise. Due to the difference of 163 workers, for the version with classic line, the company has a financial effort of 6,415 mil RON / month higher compared to the automated
technology. Related to the total annual production, this results in a higher production cost of 1.6 RON/kg.

4.3. Costs caused by energy consumption;
The accomplishment of this analysis requires the values of installed power for each type of machine and the total yields, CUM. The total yield, CUM, was calculated with the equation (1):

\[ CUM = CTU \cdot CUF \]  

(1)

where: CTU - the coefficient of useful time, the partial yield, which is dependent on the pauses imposed by equipment service and accidental repairs; CUF - machine efficiency in operation, the partial yield, which depends on pauses imposed by planned repairs: current repairs 1, RC1, current repairs 2, RC2, and capital repairs, RK.

Table 5 displays the values for the installed power, according to the machine's technical books, and for the total yields CUM.

| Automation element                                                      | No. pieces | Installed power, [kW] | CUM, [%] | Total energy consumption [kWh/year] |
|------------------------------------------------------------------------|------------|-----------------------|----------|-------------------------------------|
| Automatic can change at cards                                          | 23         | 1                     | 5        | 7010.4                              |
| Carousel for the transportation cans between cards and draw frame 1   | 2          | 2                     | 25       | 6096                                |
| Automatic can change at draw frame 1                                  | 5          | 2                     | 5        | 1524                                |
| Carousel for cans transportation between draw frame 1 and draw frame 2| 2          | 2                     | 25       | 6096                                |
| Automatic can change at draw frame 2                                  | 5          | 1                     | 5        | 1524                                |
| Carousel for cans transportation between draw frames and roving frames| 2          | 2                     | 25       | 6096                                |
| Automatic doffer at the roving frame                                  | 11         | 2.5                   | 12       | 20116.8                             |
| Carousel transportation of roving bobbins towards ring spinning frames| 2          | 2.5                   | 70       | 21336                               |
| Robots for repair ends down at the ring spinning frame                | 110        | 1                     | 80       | 536448                              |
| Automatic doffer at ring spinning frames                              | 110        | 2.5                   | 3        | 50292                               |
| Carousel transportation of cops towards winding machines              | 55         | 1.5                   | 3        | 15087.6                             |
| Equipment for the packaging of bobbins boxes                          | 1          | 2                     | 45       | 5486.4                              |
| **Total**                                                             | **677**    | **113.2**             |          | **677113.2**                        |

Knowing the automation elements, their required number calculated in concordance with the number of machines in the flow, the number of working days in one year, 254 days, results an energy consumption of 677 113.2 kWh/year. Taking into account the price of medium-voltage energy for the area covered by Enel Vest, RON/MWh, [18], so 0.45 RON/kWh, the total cost is about 304700.94 RON/year.

4.4. Amortization costs as a result of the investment effort
Starting from the FOB prices of the machines, including also transportation costs and customs duties, an investment effort of 33.181720 million RON was necessary for the modernization of the technological flow, at an average course of 1 USD = 4.4 RON, table 6.
According to the government decision HG [1], given the working regime of 24 h/day, for these equipments, an amortization period of 8 years was adopted. Under this circumstance, the amortization is 4147715 RON/year. It can be observed that, related to the total production of 4000 t/year, the level of amortization expenditure is 1.03 RON/kg yarn.

Table 6. Calculating acquisition costs and amortization.

| Automation element | No. pieces | Price [USD/piece] | Transportation and customs, [RON] | Total acquisition, [RON] |
|--------------------|------------|-------------------|----------------------------------|-------------------------|
| Automatic can change at cards | 23 | 14000 | 425040 | 1841840 |
| Carousel for the transportation cans between cards and draw frame 1 | 2 | 30000 | 79200 | 343200 |
| Automatic can change at draw frame 1 | 5 | 14000 | 92400 | 400400 |
| Carousel for cans transportation between draw frame 1 and draw frame 2 | 2 | 30000 | 79200 | 343200 |
| Automatic can change at draw frame 2 | 5 | 14000 | 92400 | 400400 |
| Carousel for cans transportation between draw frames and roving frames | 2 | 30000 | 79200 | 343200 |
| Automatic doffer at the roving frame | 11 | 16000 | 232320 | 1006720 |
| Carousel transportation of roving bobbins towards ring spinning frames | 2 | 45000 | 118800 | 514800 |
| Robots for repair ends down at the ring spinning frame | 110 | 23000 | 3339600 | 14471600 |
| Automatic doffer at ring spinning frames | 110 | 19000 | 2758800 | 11954800 |
| Carousel transportation of cops towards winding machines | 55 | 4000 | 290400 | 1258400 |
| Equipment for the packaging of bobbins boxes | 1 | 53000 | 69960 | 301160 |
| **Total** | | | | **33181720** |

5. Conclusions
Unlike the garment industry, where each machine is served by an operator, the spinning mill field in general, and of cotton spinning in particular, has reached the level of automation and aggregation unimaginable a few years ago.

Our proposal for aggregation and automation has led to the elimination of a significant number of workers who moved the intermediate products from one machine to another. Through the elements proposed for automation, eliminates a lot of workers for servicing the machines as well as some defects that appeared as a result of the manual service.

The classic technological line involves several intermediate products transferred from one machine to another, so more interruptions of the technological flow and a quality control is required at several points, after several machines, so the automation of the technological line would be profitable.

As a result of the synchronization of the various breakdowns of the intermediate products and the reaction of the automation installations in the case of the automated flow, there is a small increase of the specific consumption, 1.071, compared to 1.067 in the case of the classic flow.

By reducing with 163 the number of workers, in the case of the automated line, the production costs can be reduced by up to 1.6 RON/kg.

Of course, all these automation equipment cause an increase in energy consumption, but these are reflected to a very small increase in the total costs, 0.07 RON/kg.
The investment effort for this automation proposal is amortized over 8 years and leads to a cost increase of 1.03 RON / kg.

We notice that by decreasing the number of workers the costs decrease and by the investment made, the costs for amortization increase, but after the end of the amortization period the company will record a decrease of the costs that can be reflected either in the lowering of prices and the increase of the competitiveness on the market, or an increase in profit.

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