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TRANSPORTING DEVICES FOR PRODUCTS INTO THE PRINTING ZONE OF PAD PRINTING MACHINES: ANALYSIS, ADVANTAGES, AND DISADVANTAGES

This article investigates various types of transporting devices used in modern pad printing machines for feeding products into the printing zone. A classification based on their design features has been developed for the first time. The advantages and disadvantages of these types of transporting devices are identified, outlining issues related to positioning accuracy, productivity, and adaptation to different print runs. Recommendations are developed for selecting the optimal type of transporting device based on production specifics. Implementing the developed recommendations during equipment selection, design, or modernisation of production complexes allows for increased production productivity, reduced costs, and improved print quality.

Keywords: pad printing; pad printing machines; transporting devices; conveyors; shuttle devices; carousel devices; rotary tables.

Introduction

Pad printing is a unique method capable of decorating products with complex shapes across various industries [1, 2]. An important component of pad printing machines is the transporting device, which dictates productivity and print quality by ensuring: product holding, movement into the printing zone, and precise positioning relative to the printing elements. Modern pad printing machines demand high positioning accuracy, particularly for multi-colour applications [2]. If products are not moved quickly and positioned accurately, the entire printing process slows down, and print quality deteriorates. Consequently, the selection of an appropriate transporting device type is crucial for ensuring print quality, productivity, and the economic efficiency of the production process. The diversity in shapes and sizes of products to be printed, along with variations in print run sizes, complicates the choice of an optimal transporting device. Existing transporting systems exhibit significant differences in productivity, positioning accuracy, flexibility, and operational costs, necessitating a comprehensive analysis for an informed selection.

Despite the importance of transporting devices in pad printing machines, both domestic and international scientific literature offer limited research specifically focused on the selection and optimisation of transporting systems for pad printing machines tailored to production needs. Information presented in sources [3–7] does not allow for a definitive decision regarding the optimal transporting system for pad printing equipment for a specific printing facility, considering its production requirements. Therefore, investigating the design features of modern product transporting systems into the printing zone of pad printing machines and developing recommendations for their selection based on the needs of specific printing production is highly relevant.

The aim of this work is to analyse the different types of transporting devices used in modern pad printing machines, evaluate their advantages and disadvantages, and develop recommendations for selecting the optimal type of transporting system depending on the needs of the printing production. This will allow for an increase in the productivity of pad printing machines, improvement in print quality, and reduction in the cost of product decoration.

Methods

This study employed a research methodology based on the analysis and synthesis of existing information regarding product transporting devices used in modern pad printing machines. A comprehensive review of relevant scientific and technical literature, industry data collection (from technical specifications, product documentation, catalogues), a structured comparative analysis to evaluate the identified types of transporting devices, and synthesis and formulation of recommendations for selecting the optimal type of transporting system were conducted.

Results

An analysis of the design features, construction, and operating principles of modern pad printing equipment has enabled the development of a classification for transporting devices in pad printing machines, presented in Fig. The equipment offered by leading global manufacturers, including Tampoprint (Germany), Inkcups (USA), Comec Italia (Italy), microPrint (Switzerland), Teca-Print (Switzerland), Morlock (Germany), Ever-Bright Printing Machine (China), and others, was analysed.

Product transportation into the printing zone can be accomplished using linear and carousel devices. Carousel devices typically consist of rotary tables onto which the products to be printed are mounted. Such tables facilitate the movement of products between single-colour printing sections or between printing units of a multi-colour module. Linear transporters, in turn, can be of the shuttle type or conveyor type. Shuttle-type transporting devices allow for the printing of one product at a time, with either pneumatic or servo drives used for shuttle actuation. In comparison, conveyor transporting devices can hold multiple products simultaneously. They can be constructed in either vertical or horizontal configurations.

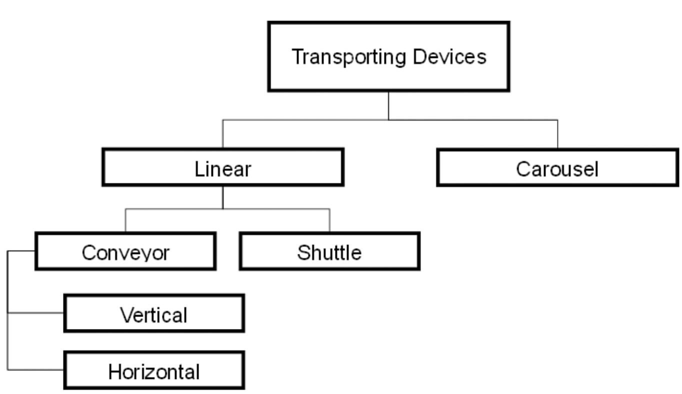
Conveyor transporting devices in pad printing utilise structural elements onto which products are fixed, moving them through various printing and processing stages. Conveyor systems are often integrated with automated loading and unloading systems to ensure a continuous production process [8]. The conveyor is typically driven by electric motors, allowing for adjustable product movement speed [9].

A characteristic feature of *vertical* transporting devices is that the plates for mounting products move in a vertical plane [10]. This necessitates fixing the products to hold them across the entire conveyor surface. If products are not fixed, only the upper section of the conveyor becomes the operational area. The advantage of vertical transporting devices is that they require a minimum of space in width, while they can have any necessary length. Thus, vertical conveyors are better suited for large-sized or non-standard products, whereas compact items are more easily transported by horizontal conveyors.

A feature of *horizontal* conveyor-type transporting devices is that all products are placed in a single plane [11]. Such devices are wider than vertical ones but do not require product fixing and allow the entire surface to be used for easy placement and monitoring of the items being printed. These transporting devices facilitate easy loading and unloading of products at a single position. Furthermore, increasing the number of positions only leads to a linear extension of the conveyor.

Conveyor transporting devices are ideally suited for mass production and processing large quantities of products [9, 11]. The continuous flow of products through printing and processing modules ensures high throughput and reduces the processing time per item, which allows achieving a printing speed of 1000–1500 impressions per hour and higher. Conveyor systems can be readily integrated with other automated equipment, such as loading and unloading robots, pre-treatment systems (e.g., cleaning or primer application), and post-treatment systems (e.g., drying), creating fully automated production lines [8].

However, in some cases, conveyor systems may offer slightly lower printing accuracy (on average ±0.1–0.2 mm) compared to rotary



Classification scheme of transporting devices for products into the printing zone of pad printing machines

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tables. The intermittent movement of the conveyor can introduce minor vibrations or displacements [11], impacting the quality and accuracy of the printed image, especially in multi-colour printing with strict registration requirements. Consequently, a disadvantage of conveyor transporting devices is the potential need for additional positioning devices and systems to ensure precise product fixation and alignment relative to the printing elements. Specialised fixtures, clamps, or guides are used for this purpose, holding the product in the required position during ink application [7]. Modern conveyor systems equipped with high-precision drives and product fixation systems significantly mitigate this drawback. For instance, Inkcups (USA) offers specialised fixtures for pad printing conveyor systems [12]. Control sensors and visual recognition systems are also employed to verify correct product positioning before printing and can make necessary adjustments [13]. In linear motion conveyor systems, precision servo drives are often used to ensure uniform and controlled conveyor speed, further enhancing printing accuracy [14]. Research [6, 15–17] suggests using cam mechanisms for intermittent motion, which can provide precise movement according to a predefined periodic motion law without resorting to expensive precision servo drives.

A characteristic feature of *shuttle-type* transporting devices is that only one product is mounted on such a device, moving according to a set program between printing stations. They are commonly used for multi-colour printing but also allow for multiple applications of the same ink colour without moving the product, thereby creating a thicker ink layer of a single colour. After ink application is complete, the product returns to its initial position. Shuttle movement can be achieved using pneumatic or servo-driven mechanisms, ensuring precise positioning under each printing element [18].

One key advantage of shuttle devices is the ability to program the sequence of ink applications and the number of applications for each colour. This allows for the creation of complex multi-colour images with a high degree of control at each printing stage. The operator can define the ink application order, the number of repeat applications for a single colour, shuttle speed, and dwell time between applications to ensure proper ink drying [19]. This enables optimisation of the printing process for different product types (which differ in shape, size, smoothness of the printable surface, etc.) and achievement of the desired image quality. For example, the Inkcups ICN-2500 machine features a programmable shuttle table ensuring precise part movement between printing modules [20].

Shuttle devices offer high flexibility when working with diverse product types, if the enterprise needs to frequently readjust the printing machine for products that differ in size, shape, etc. The shuttle design allows for easy installation and changing of specialised fixtures designed to hold products of various shapes and sizes [18]. This makes them an optimal choice for production environments with a wide product range, where specific ink application

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requirements and frequent equipment changeovers for new product types are common.

A disadvantage of shuttle devices is their typically lower productivity (on average 400–600 impressions per hour) compared to rotary tables and conveyors, especially for large print runs [18]. The back-and-forth movement of the shuttle between printing modules takes longer than the unidirectional intermittent movement of other types of transporting devices. Therefore, shuttle devices are more frequently used for small print runs (up to 1000 impressions) to medium print runs (1000–10000 impressions) where flexibility and the ability to perform complex printing tasks are prioritised.

Shuttle devices require a specialised approach to programming and maintenance [18]. Programming the shuttle's movement sequence, printing parameters for each module, and setting dwell times requires skilled personnel. Maintenance of the shuttle mechanism's mechanical components, including pneumatic cylinders or servo drives, is also more complex compared to other types of transporting devices.

Carousel-type transporting devices ensure the sequential movement of products mounted on a rotary table. Table rotation is driven by pneumatic or electric actuators, providing precise product positioning in the printing zone [21]. The stable and rigid construction of the table guarantees reliable product positioning during printing [22], minimising vibrations or accidental movements that could degrade print quality, which is particularly important for multi-colour printing. For instance, pad printing equipment from microPrint (Switzerland) with carousel-type transporting devices can achieve colour registration accuracy up to ±0.05 mm [23]. The size of the rotary table depends on the dimensions and number of products being printed simultaneously on the table [21].

Rotary tables are ideally suited for production environments with smaller print runs (up to 1000 impressions) and high demands on print quality (for example, requirements for color registration accuracy of ±0.05–0.1 mm). They offer a balance between accuracy and relative ease of use, allowing for quick setup and changeover for decorating different product types, making them an optimal solution for small print runs (up to 1000 impressions) and medium print runs (1000–10000 impressions).

The main disadvantage of carousel transporting devices is that even a small increase in the number of positions leads to a significant increase in the overall dimensions of the table. Each additional position requires space on the rotating surface, increasing its diameter and, consequently, the total area occupied by the machine [21]. This is a considerable drawback in production facilities with limited space. Accordingly, this aspect must be considered when planning the production layout and the ergonomics of the operator's workstation for loading and unloading products.

Another significant drawback of rotary tables is their lower productivity (on average 600–800 impressions per hour) for large print runs (more than 10000 impressions) [21] compared to other types of

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transporting devices, such as conveyors. The limited number of products simultaneously mounted on the rotary table reduces the overall speed of printing large quantities.

Comparative analysis of advantages and disadvantages of transporting devices

The choice of transporting device type depends on several factors that must be considered during the design of the production process. These include product size and shape, print run volume, and requirements for print quality and positioning accuracy. Economic factors, such as equipment cost, maintenance, and energy consumption, also influence the selection. Each type of transporting system has its own advantages and disadvantages, which should be weighed according to these factors. The results of the analysis are summarised in Table.

Advantages, disadvantages, and selection criteria for product transporting devices into the printing zone of pad printing machines

Characteristic	Carousel devices (rotary tables)	Conveyors	Shuttle devices
Advantages	— High positioning accuracy (±0.05–0.1 mm), — capability for simultaneous multiple operations, — convenient for small print runs (up to 1000 impressions)	— Ability to accommodate many product positions without significant size increase, — convenient for large print runs (more than 10000 impressions), — high speed (1000–1500 impressions per hour), — integratable with automation, — capability for simultaneous multiple operations	— Programmable ink sequence, speed, dwell time, and application count per colour; — flexibility for various product types (versatility); — high positioning accuracy (±0.08–0.12 mm)
Disadvantages	— Increased dimensions with more positions, — limited productivity for large print runs (more than 10000 impressions), — difficulty printing large items	— Requires additional devices for precise positioning, — lower accuracy (on average ±0.1–0.2 mm) compared to rotary tables and shuttle devices	— Lower productivity (print speed) — 400–600 impressions per hour, — complex programming and maintenance, — inability for simultaneous multiple operations

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End of Table

Characteristic	Carousel devices (rotary tables)	Conveyors	Shuttle devices
Color registration accuracy, mm	±0.05–0.1	±0.1–0.2	±0.08–0.12
Print speed, im-pressions per hour	600–800	1000–1500+	400–600
Small print runs (up to 1000 impressions)	+++	+	++
Medium print runs (1000–10000 impressions)	++	++	+++
Large print runs (more than 10000 impressions)	+	+++	+
Decorating products requiring high print accuracy (incl. multi-colour)	+++	++	++
Decorating various product shapes/sizes (versatility)	++	+	+++
Need for printing process programming	+	+	+++
Change in equipment dimensions (with increased positions)	Increases significantly	Increases slightly	Depends on configuration

Legend:
+++ — Most suitable.
++ —Acceptable to use.
+ — Possible, but not rational to use.

Discussion

Thus, carousel devices (rotary tables) provide high printing accuracy (±0.05–0.1 mm) and are an optimal solution for small print runs (up to 1000 impressions) to medium print runs (1000–10000 impressions) where print quality is a priority. However, increasing the number of printing positions leads to a significant increase in equipment dimensions, and productivity (which is 600–800 impressions per hour) is insufficient for large print runs (more than 10000 impressions).

Conveyor transporting devices, conversely, are ideally suited for large print runs (more than 10000 impressions). They allow for the processing of a substantial number of products without significantly increasing equipment size. However, achieving high positioning accuracy (which exceeds the average values for this type of equipment of ±0.1–0.2 mm) on conveyors often requires additional devices, and the accuracy itself may be somewhat lower compared to rotary tables.

Shuttle devices offer high flexibility and the ability to program complex printing sequences, making them attractive for manufacturers with diverse product ranges and specific printing needs. However, their productivity is generally lower than that of rotary tables and conveyor systems and is 400–600 impressions per hour, and their operation requires specialised knowledge in programming and maintenance.

Therefore, for small print runs with high accuracy requirements, carousel devices are advisable. For large print runs with less stringent accuracy requirements, horizontal or vertical conveyors are preferable. Shuttle devices are optimal for complex printing schemes involving the application of multiple ink layers.

Conclusions

The analysis of the main types of modern transporting devices for pad printing machines has shown that each possesses unique advantages and disadvantages, determining their applicability for different production needs. Selecting the optimal transporting device for a pad printing machine in a contemporary printing facility represents a compromise between factors such as print run size, required accuracy and print quality, flexibility and versatility (for various shapes and sizes of products to be printed), and equipment cost. A thorough analysis of these requirements will enable the selection of the most effective solution for the needs of a specific printing facility.

Future developments in these technologies can be expected, aimed at enhancing the speed, accuracy, and flexibility of transporting systems for pad printing machines. Further research could also focus on developing hybrid transporting systems that combine the advantages of different types, offering improved performance and versatility characteristics. Of particular interest is the development of intelligent control systems for transporting devices capable of adapting to different product types and printing modes.

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У статті досліджено різні типи транспортувальних пристроїв, які використовуються у сучасних тамподрукарських машинах для подавання виробів у зону друку. Вперше розроблено їх класифікацію за конструктивними особливостями. Визначено їхні переваги та недоліки, окреслено проблеми, пов’язані з точністю позиціювання, їхньою продуктивністю та адаптацією до різних накладів. Розроблено рекомендації щодо вибору оптимального типу транспортувального пристрою залежно від специфіки виробництва, зокрема розміру й форми виробів, накладу, необхідної якості друку. Впровадження цих рекомендацій під час підбору обладнання, проєктування або модернізації виробничих комплексів дає можливість підвищити продуктивність виробництва, знизити собівартість та підвищити якість друку.

Ключові слова: тамподрук; тамподрукарські машини; транспортувальні пристрої; конвеєри; човникові пристрої; карусельні пристрої; поворотні столи.

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