NOVEL ROPE-FREE MECHATRONIC ELEVATOR SYSTEM TO AUTOMATION OF TRANSPORT IN AGRICULTURAL FARMS

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Abstract. It is difficult to imagine a modern agricultural holding without modern means of automation. Indeed, holdings that are ever larger and specialized in specific areas of production force their owners to apply more efficient and technologically advanced engineering solutions. The current trend of development concerns transportation systems used in agricultural production, storage systems, systems for dosing feed and manufactured products as well as the majority of modern machinery and equipment used for production and cultivation of plants and breeding of animals or gardening, above all. This allows today's farmer (entrepreneur) to improve a series of daily activities with lesser involvement in direct physical labor, thus adding additional reserves of time and energy for increasing the scale and scope of other activities and enabling better management of capital, among other things. This article presents a novel rope-free mechatronic multi-car elevator system for vertical and horizontal transport and simultaneous integration of movement in two directions, which is used in Automated Storage and Retrieval System (ASRS). The elevator drive is based on a mechatronic planar positioning system with an aerostatic bearing. An original solution of a mechatronic rope-free elevator can be used for transportation of animals, agricultural produce (vegetables, fruit, corn, seeds, etc.), also suitable for transportation of hay, straw, and similar materials and products that are used for animal husbandry and agriculture. The structure and the principle of operation of the rope-free elevator are presented. Advantages are using of the mechatronic rope-free multi-car elevator in novel agricultural buildings (hay loft, barn for animals, granary, root cellar, hay shed, etc.).

Keywords: planar positioning system, rope-free elevator, automation of transport, agricultural farms, ASRS.

Introduction

Currently, automation, industrial and service robotics as well as appropriate use of information technology may contribute to broadly understood automation of agricultural holdings. In recent years, implementation of innovative automated solutions in many areas of services for agriculture has become increasingly noticeable in agricultural holdings in Poland and other European Union countries. For example, modern automated systems installed in newly built cowsheds on dairy farms now perform strictly defined functions (services) related to milking cows, maintaining cleanliness, feed batching and compaction, removal of excrements and daily animal care treatments [1]. This is intended to increase animal production while meeting requirements concerning methods of feeding and supplying feed to livestock [2; 3]. Numerous publications and reports in the media contain information about other automated systems, e.g., successfully implemented in beef cattle farms, pig farms, sheep farms, and chicken farms [4-7]. Network systems supported by satellite navigation, telemetric systems and the Internet [8-12] are another interesting group of innovative solutions that support human labor on farms. They are mainly intended for monitoring agricultural production processes and animal health condition. They are used, among other things, for rational crop management in order to reduce consumption of fertilizers and pesticides used in crops. Such systems can also manage a single building intended for agricultural activity or an entire farm. Thanks to them, a farmer can browse data concerning production and climate conditions in fields, greenhouses, hatcheries, and other buildings (rooms) on the farm, on the computer. These systems enable monitoring and control of automated systems on a farm, e.g., automatic lighting, climate control, fire and smoke detection, auto lock and release doors, humidity and moisture control, pre-set wash times, feeder control, remote mobile connectivity [13-15].

Automated goods accumulation and warehousing solutions are mainly used in modern libraries, warehouses, store houses and tool-rooms today. They are termed in the literature as Automated Storage Retrieval Systems (ASRS) [16-22]. These systems were first implemented and used for distribution and in production environments as early as the 1950s. ASRS are a modern way to optimize and improve methods of storing, loading and unloading specific goods as well as to transport materials from position to position within a given space. Effective application of solutions of this type is linked to reduction of direct labor [19; 22], energy savings, repeatability of operations, reduction of the number of erroneous decisions as well as to reduction of the costs of controlling services, maintenance costs and costs of constructing the facilities in which ASRS are to be applied [17]. To translate these attributes to the field of agricultural solutions, their implementation into day-to-day agricultural practice is economically justified, particularly in large, specialized breeding farms, with up to several hundred heads of livestock. Thanks to the application of automated transport systems, the scale of agricultural and animal production increases while simultaneously meeting the requirements concerning rational management methods. This is all so that rational planning of the agricultural production cycle, which will ultimately translate to future revenue, is also compliant with the requirements of the European Union. When undertaking long-term investments related to the expansion of new facilities and modernization of the existing infrastructure, a developing modern agricultural holding, oriented towards profit, should consider the application of flexible mechatronic transportation systems and automated, intelligent systems for accumulation and storage of agricultural crops, fertilizers and pesticides used in crops, or for feed batching to animals, etc.

The main goal of this article is to present a novel rope-free mechatronic multi-car elevator system for vertical and horizontal transport and simultaneous integration of movement in two directions. The mechatronic rope-free multi-car elevator can be used in novel agricultural stores (for crops, fertilizers, animal feed, etc.) and agricultural buildings (hay loft, barn for animals, granary, root cellar, hay shed, etc.) as the transport component of an ASRS system. The application of solutions of this type has become feasible for a growing number of farmers due to growth of investment outlays in agriculture. According to the data from the Polish Statistical Yearbook of Agriculture 2015, outlays in the years from 2005 to 2014 amounted to a total of PLN 2842.5 million. Investments concern outlays for: buildings and structures; machinery, technical equipment and tools; and transport equipment.

Materials and methods

An original solution of a mechatronic rope-free elevator system has been proposed in response to the transport needs of automated ASRS systems in agricultural holdings. It can be used for transportation of animals, agricultural produce (vegetables, fruit, corns, seeds, etc.) and is also suitable for transportation of hay, straw, and similar materials and products that are used for animal husbandry and agriculture.

Fig. 1 presents the general concept of the ASRS. The main components of an ASRS are racks, multi-cabin elevator with cranes (manipulators), aisles, input/output-points, and pick positions. An example mechatronic solution with a final effector (element 14 – Fig. 2) serving for loading/unloading of agricultural goods and products may be built on the foundation of the solutions presented in papers [23; 24].

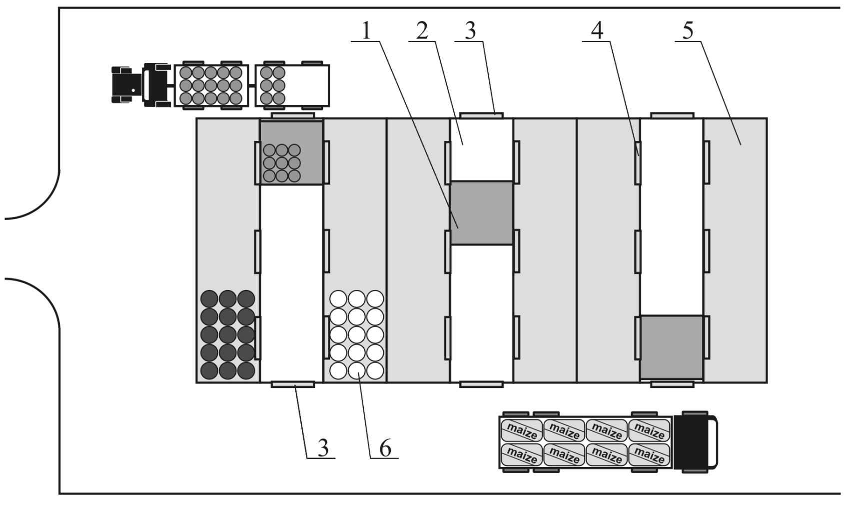

Fig. 1. **Main elements of ASRS:** 1 – elevator cabin with crane; 2 – aisle (shaft); 3 – input/output-points; 4 – pick positions; 5 – racks; 6 – agricultural produce

Fig. 2 presents components of the mechatronic rope-free elevator for transport in the vertical and horizontal direction as well as in both directions simultaneously in the example configuration [25].

The main components of the cabin's planar positioning system are immobile planar stators (7) installed on the aisle (shaft) surface (2) and mobile planar forcers (13) installed on the exterior side surfaces of the cabin (1). Electromagnetic drive modules installed on the bearing surfaces of planar forcers (13) are responsible for moving the cabin (1) over the track comprising planar stators (7) and for attraction of the cabin (1) to the stators (7). Planar stators (7) serving for movement of the cabin (1) can form a track of any shape or can be distributed over the entire surface of the aisle (shaft) (2) walls [25]. This solution allows for movement of the cabin (1) in the horizontal and vertical direction as well as in both directions at the same time, enabling travel to any pick position (4) of the racks.

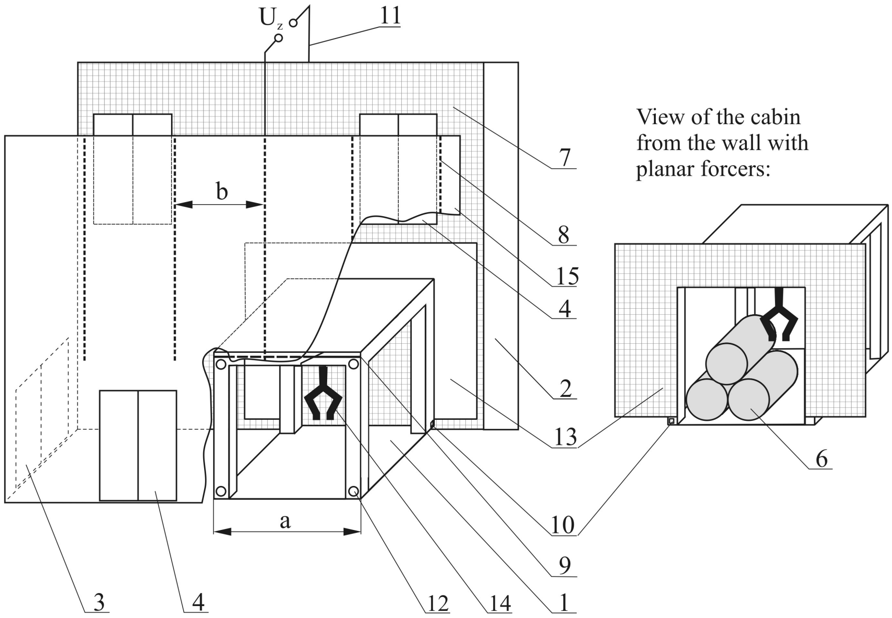

Fig. 2. **Main elements of mechatronic rope-free elevator system for ASRS**

The cabin (1) moves over the shaft (2) without coming into contact with it thanks to the application of aerostatic bearings. A layer of air with pressure greater than atmospheric pressure is generated between the forcers (13) and stators (7), forming an air cushion that balances the forces of electromagnetic attraction of the forcers (13) to the stators (7), among others. The above necessitates equipping of every cabin with its own source of compressed air, which is indispensable for generating the air cushion between the planar stators (7) and the planar forcers (13). A compressor with a pressure vessel or a pressure vessel by itself can be installed on the elevator cabin. Another option is to install a station generating compressed air in the shaft, to which the cabin (1) would have to travel and connect to (dock) in order to replenish air in the pressure vessel.

In order to ensure a constant height of the air gap over the entire area of stator/forcer inter-operation, a system of supporting elements (12) is made up of kinematic pairs with three degrees of freedom, all rotating.

Electrical supply to the cabin (1) is carried out by means of a contact system (Fig. 2). A contact system (8) for power supply is distributed on the wall (5). Electricity flows from power supply cables (8) through the current collector (9) to the cabin's (1) electrical system powering individual forcers (13), the compressor, which is required for generating the air cushion, and the control system along with the operator's panel and cabin lighting. From the receivers in the cabin (1), electrical current flows through the return current collector (10), stators (7) and the cables connected to them (11). Electrical power supply to the cabin necessitates the distribution of individual power supply cables (8) at a distance b less than distance a of the current collector (9) placed on the cabin wall. This solution ensures uninterrupted contact of current collectors (9) with the network of power supply cables (8) during movement of the cabin (1) over a track of any shape made up of stators (7).

Every pick position in the proposed system is specially marked. Bar codes are used to do so. Depending on the current needs of a farm, QR codes offering greater information coding capabilities can also be used for this purpose. The same applies to marking of goods and products stored in the proposed ASRS mechatronic system. Thanks to the implementation of such a solution, and ASRS, besides its normal functionality – it knows where to deposit the given goods or where to retrieve them from, it can also react to the operator's incorrect decisions in terms of product pick positions. By reading information from codes both on the goods and at the storage/retrieval site using a laser scanner, this information can be processed appropriately to avoid future errors related to, e.g., improper issue of pesticide, leading to its improper use in the agricultural production process. Other elements of the ASRS system besides those mentioned above are not accounted for in this paper and are not the subject of the authors' research at this time.

Results and discussion

Strict cooperation between the scientific community and farmers is required so as to more rapidly develop and improve innovative automated systems for agricultural purposes. A thorough understanding of operating conditions and the individual needs of a given farm will allow for more effective development of useful solutions. Automation of transport, accumulation and storage processes for crops, fertilizers and pesticides, feed batching to livestock allows for faster and more precise resource management, speeds up the transport of agricultural products to consumers, increases repeatability, and more clearly improves the quality of the offered service.

The solution presented in this paper has many indisputable advantages [25]:

- transport can take place vertically and horizontally as well as in two directions of movement simultaneously,
- the elevator is rope-free – there is no need to install a machine room or lines on which cabins would be suspended in aisles (shafts),
- the application of aerostatic bearings in the drive system eliminates wear between inter-operating surfaces of stators and forcers; there is no need for periodical lubrication of guides, which translates to limitation of activities related to maintenance of the transportation system and reduction of the operating costs,
- in the case of an emergency situation related to, e.g., loss of electrical power or pneumatic supply required for generation of the air cushion, because electromagnetic drive modules contain strong rare earth magnets, the cabin will not fall but rather be drawn to the shaft wall, where it will remain safely until the problem is solved by technical teams or the emergency power supply system is activated,
- the multi-cabin system enables optimal configuration of the number of cabins moving in the shaft over a track of arbitrary shape, which allows for rapid and flexible reaction to actual transportation needs within a given large-area agriculture building.

Based on a mechatronic rope-free multi-car elevator, a modern system for accumulating and storing crops, fertilizers and pesticides used in crops as well as animal feeds at farms can be developed. This solution will have many advantages:

- a bar code (or QR code) identification system implemented on the mechatronic rope-free elevator makes it possible to unequivocally identify goods (products) and their storage locations,
- application of an automated warehouse with mechatronic rope-free elevator saves a lot of space (no additional space needed for introducing and maneuvering other machinery and equipment that are typically used, e.g., forklifts, telescopic loaders, etc.), which can be used as an additional surface for storing other products,
- thanks to the capability of combining movement on two axes at the same time, the time of internal transport is reduced in comparison to typical transport solutions,
- it provides the capability of increasing the precision and speed of movement of an elevator bearing goods or products, which significantly improves the system's performance,
- application of such an elevator will foster the implementation of new motion control techniques, the parameters of which can be flexibly selected depending on actual needs (e.g., different parameters for transport of solid, loose materials, liquid products, etc.).

Of course, the final form of the ASRS's design must be adapted to the final recipient. It is he who will decide on the configuration, demand and load-bearing capabilities of the transport unit, the size of the system, the height/width/depth and load-bearing capacity of shelving where products will be stored, the form of the final effector situated on the transport system, the number and locations of retrieval sites and the number of units required for delivering products, as well as on the packaging itself and the form of goods. Requirements specified in this fashion will make it possible to select and optimize the system parameters, e.g., to choose the appropriate operating strategy, minimize the product delivery time. More on the subject of aspects of designing example ASRS solutions can be found in papers [17; 19; 22].

Conclusions

1. Implementation of automated transport systems in agricultural holdings as well as their guarantee and post-guarantee maintenance is an expensive endeavor, but despite this, farmers and breeders are investing in modern technologies that can contribute to facilitating day-to-day activities and making them more efficient. From a long-term perspective, investing in innovative technologies makes it possible to limit direct human labor, reduce the time of performing typical activities, and thus contribute to reducing the final operating costs.
2. Thanks to the application of planar positioners as a source of rope-free drive for the ASRS transport system, the flexibility of the entire system increases, in contrast to typical solutions based on rail and overhead crane systems. Potential further expansion and adaptation of the solution to a farm's actual needs, e.g., in the event that the scale of production is increased or storage rooms are expanded, is also much easier.
3. Multiple forcer units can operate simultaneously and without collision on a single surface of stator units to service shelving areas, which will reduce the operating time of the ASRS system.
4. The solution of a mechatronic transport system for ASRS store houses will be equipped with a specialized manipulator with a final effector appropriate for loading/unloading of agricultural products and goods over the course of further work on the project as well as with software controlling and optimizing operation of the system, cooperating with the bar or QR code system.

Acknowledgement

This research has been done as a part of a statutory research of the Department of Automatic Control and Robotics, Faculty of Mechanical Engineering which is funded by Bialystok's University of Technology, Poland.

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