IMPROVING THE LOGISTICS OF THE MULTI-FLOOR ASSEMBLY MANUFACTURING

Logistyka pionowego transportu wewnętrznego w montowni wielokondygnacyjnej

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A b s t r a c t: The concordance of the vertical transport carrying capacity and of the performance of a multi-floor assembly manufacturing is one of tasks of production logistics. This paper defines the performance of multi-floor assembly manufacturing, depending on the number of parallel working flexible assembly cells, the weight or volume distribution of the finished product on the floors, the floor area occupied by the assembly production and vertical transport, the carrying capacity and number of freight elevators, time of their working cycle. The conditions to achieve the rational performance of multi-floor assembly manufacturing are revealed, allowing to determine the number of parallel working flexible assembly cells, the number of floors taking into account the height and the production of area floors, performance and footprint flexible assembly cells, the technical characteristics of the freight elevators and the area occupied by them. It provides the conditions for effective operations of the multi-floor assembly manufacturing and servicing, the vertical transport.

K e y w o r d s: flexible assembly cells, elevators, performance, time of cycle, number of floors

S t r e s z c z e n i e: Dopasowane pojemności i wydajności pionowego transportu w montowni, usytuowanej w obiekcie wielokondygnacyjnym, jest jednym z zadań logistyki produkcji. Wydajność montażu wyrobu określona jest w zależności od: liczby równoległych elastycznych komórek montażowych, masy i/lub objętości wyrobu końcowego, powierzchni podłogi zajmowanej podczas montażu oraz wydajności transportu pionowego, pojemności i liczby wind towarowych oraz od czasu cyklu produkcyjnego. Warunki do uzyskania skutecznego działania wielokondygnacyjnych montowni, wyznaczają: liczba równoległych elastycznych komórek montażowych, liczba pięter, wysokość i powierzchnia przestrzeni produkcyjnej, wydajności elastycznych komórek montażowych, właściwości techniczne wind towarowych wraz z zajmowanym przez nie obszarem. Uwzględnienie powyższych uwarunkowań i zaproponowanie logistycznych rozwiązań sprawia, że możliwe jest zapewnienie warunków dla skutecznego funkcjonowania produkcji montażowej wielopoziomowej i obsługi IT, transportu pionowego.

S ł o w a k l u c z o w e: elastyczne komórki montażowe, windy, wydajność, czas cyklu, liczba kondygnacji

Introduction

The multi-floor cellular assembly manufacturing is widely used in large cities and megacities with high-density populations due to limited areas for industrial development and also the necessity of unloading of transport streams. They are used for the manufacture of small-sized products based on modular technology [1, 2, and 3]. Assembly manufacturing is placed on each floor of the building in the form of autonomous flexible assembly cells (FACs), which are served by autonomous groups of assembly personnel. FACs contain the groups (two or more) flexible assembly lines (FALs), which are alternately readjusting as manufactured products are changed. FACs have high performance, the ability to quickly reprogramming to produce other products and are suitable for products with a variety of types and variants [1, 3]. The assembling products of the FACs are intended for sale to various customers of metropolitan agglomeration, including, as components of more large products assembled at other plants.

The FACs layout on the floors is carried out taking into account weight or volume of the finished product. The products of less weight or less volume are produced on the overhead floors of multi-floor manufacturing. For instance, distribution of weight or volume of the assembling products on floors can be accepted as inversely proportional to the height of floor location [2]. This approach places heavy and bulky equipment at the lower floors and, thus, decrease the construction costs of multi-floor manufacturing by reducing the load on its bearing structure of the building, and also on setting of technological equipment [1, 2].

Presently planning of an assembly equipments layout from the point of view of the transport streams minimization into every floor and between floors successfully realized by the well known programs: CRAFT, SPACECRAFT, COFAD, ALDER, CORELAP, PLANET, PLANT-4D, etc. [1]. It should be noted that questions of multi-floor manufacturing layout (mainly in the chemical industry), vertical transporting of substances and materials, the choice of the number of building floors are considered in the large enough number of research studies [1, 4]. Nevertheless, the actual for researches are remained the questions, related to logistics of the vertical transport streams and their co-operating with horizontal transport streams taking into account the weight or volume distribution of the assembling product on the floors, the performance of the FACs and layout of storage facilities of the multi-floor manufacturing. It is important to mark that limitation of the FACs performance is related not only to the limited production areas, the strength of the building structure, but also with the carrying capacity of the freight elevators of multi-floor manufacturing.

The aim of the paper is to improve the logistics of multi-floor assembly manufacturing taking into account the performance of the used FACs, weight or volume distribution on the floors of the assembling products and the carrying capacity of the freight elevators.

The concordance of the manufacturing performance and transport capacity

The layout of the FACs in multi-floor manufacturing depends on many factors, among that basic are the type and weight of the assembling products, and also the applied technological process. One of the conditions of the FACs layout in multi-floor assembly manufacturing is to minimize the production of basic and auxiliary transport streams, defining movement the component, products, tools, consumables and waste [1, 3, and 6].

As an example on Fig. 1 the charts of the FACs layout are presented in multi-floor manufacturing. Multi-floor manufacturing includes the FACs 1 with the FALs 2 and 3 accordingly for the assembly of components and products; freight elevators 4, readjusted trolleys 5, 6, 7, 8, 9, accordingly with the components, finished products, defective components, and waste. FACs are equipped with areas for incoming inspection 10 and adjustment 11 of the component; auxiliary assembly features 12; output control 13, repair and adjustment 14, packing and loading 15 of finished products. Building for manufacturing contains: a main storage 16 and storages 17 for tools and supplies on each floor, administrative and sanitary facilities 18, stair grounds and passenger elevators 19 and sound-absorbing barrier 20.

Delivery of the components, tools and consumables in each FACs, shipping of products and wastes from it is carried out by freight elevators and readjusted trolleys. The supply of assembly manufacturing by readjusted trolleys is most effective on a method „Kanban Cards". The trollies after loading can be moved on the floor along the routes shown in Fig. 1. Filled trolleys with finished products or wastes are shipped on the main storage. The receiver control and the formation of components complete for assembly, including packaging, is carried out in main storage of the assembly manufacturing, which is located on the ground floor (floor number 0) of the building.

After completion of the preparatory work in the areas 10–12, the components arrive at the two in parallel working FALs 2, where the components are puted together in assemblies that is, which are delivered to the two parallel working FALs 3 for the final assembling of the product. Four FALs 2 and 3 are realized the consistently-parallel works of the automated assembly equipments.

Time of cycle of the freight elevators work at consistently (shuttle) maintenance of the FACs on each floor of the multi-floor manufacturing is determined with the following expression:

$$T_C = 2k_C hF^2 / 3600\nu\varepsilon, \qquad (1)$$

where: T_C – time of cycle of the freight elevators work, h; k_C – the coefficient of losses of time cycle of a work of the freight elevators, the values of that are in limits k_C = 1,05–1,6 (with the increase of floors number of assembly manufacturing a value of the coefficient aspire to unit); F – the number of the building floors, since the first, on that FACs are layouted; h – the height of building floor, m; ν – speed of uniform movement of the freight elevators, m/s; ε – the number of the freight elevators.

The values of the coefficient k_C depend also on the frequency of delivery tools and consumables, waste disposal, breakdowns of the freight elevators, availability of spare freight elevators in the building, etc.

The weight (gross) and volume distributions of the assembly products on the floors will be given in a kind:

$$W_n = \vartheta_W W_1 / n; \qquad (2)$$

$$V_n = \vartheta_V V_1 / n, \qquad (3)$$

where: W_n, W_1 – the maximum weight (gross) of the assembling products accordingly on the n-th floor and on the ground floor of the multi-floor manufacturing, N; V_n, V_1 – the maximum volume of the assembling products accordingly on the n-th floor and on the ground floor of the multi-floor manufacturing, m^3; ϑ и ϑ_V – the coefficients of the distribution accordingly of the weight and volume of the finished products, the values of that depend on dynamic descriptions of the technological equipment and strength of the building structure; n – the number of floor since the second floor.

The weight and volume performance of the FACs during their consistently-parallel work on the n-th floor are defined [5]:

$$G_{W.n} = 3600 \cdot \vartheta_W W_1 q_n m_n p_n K_{0.n} / \\ / n\left(1 + m_n p_n K_{0.n} t_{J.n} + m_n p_n^2 K_{0.n} t_{S.n}\right); \qquad (4)$$

$$G_{V.n} = 3600 \cdot \vartheta_V V_1 q_n m_n p_n K_{0.n} / \\ / n\left(1 + m_n p_n K_{0.n} t_{J.n} + m_n p_n^2 K_{0.n} t_{S.n}\right), \qquad (5)$$

where: $$t_{S.n} = \sum C_{i.n} + t_{e.n}; \qquad (6)$$

$G_{W.n}$ – the weight performance of the FACs on the n-th floor, N/h; $G_{V.n}$ – the volume performance of the FACs on the n-th floor, m^3/h; q_n – the number of the working FACs on the n-th floor, pcs; $K_{0.n}$ – the technological performance of all assembling process befor his crushing on the consistently working FALs on the n-th floor, pcs/s;

p_n – the number of the consistently working FALs on the n-th floor; m_n – the number of the parallel working FALs on the n-th floor; $t_{J.n}$ – time of idling of the group FALs on the n-th floor, s; $t_{S.n}$ – losses of outside cycle time of a FAL on the n-th floor, s; $t_{e.n}$ – losses of time for repairs and readjusts of a FAL on the n-th floor, s; $\Sigma C_{i.n}$ – losses of time for tools of a FAL on the n-th floor, s.

On the basis of dependences (1) – (6) we will find a rational number of the parallel working FALs in composition of the FACs on the n-th floore:

$$m_{n.w(v)} = \frac{n\varepsilon\left(Q_{W(V)} - \lambda L_{W(V)}\right)}{3600 \cdot T_C \vartheta_W W_l q_n p_n K_{0.n} - n\varepsilon\left(Q_{W(V)} - \lambda L_{W(V)}\right)\left(p_n K_{0.n} t_{J.n} + p_n^2 K_{0.n} t_{S.n}\right)} \quad (7)$$

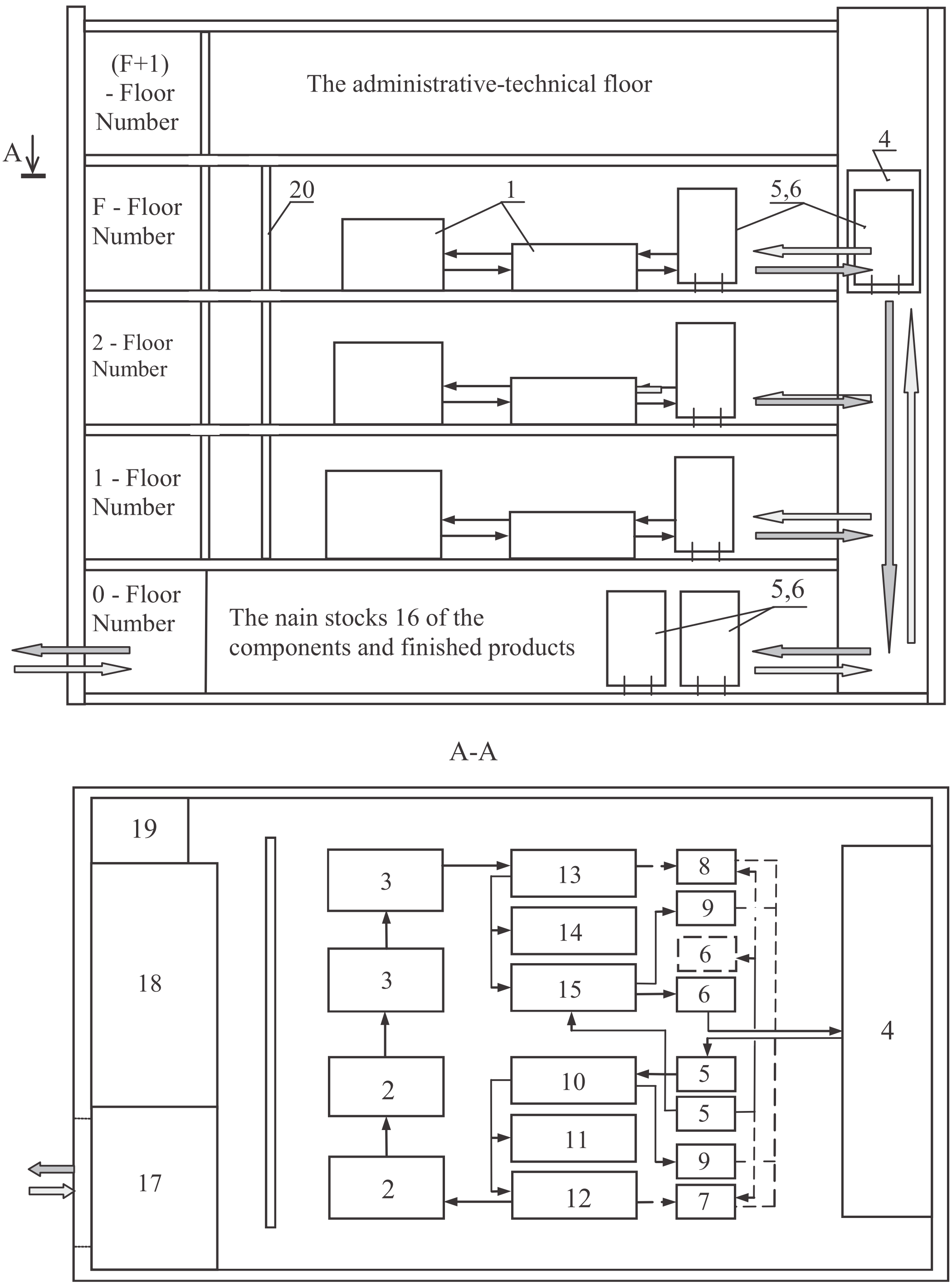

Fig. 1. Charts of the FACs layout on the floor of the multi-floor assembly manufacturing and technological streams: – basic technological streams, – auxiliary technological streams

Rys. 1. Schemat rozmieszczenia FACs dla wielokondygnacyjnej produkcji montażowej w technologii płynnej: podstawowe strumienie technologiczne i pomocnicze strumienie procesowe where: $m_{n.w}$, $m_{n.v}$ – the calculation rational number of the parallel working FALs in composition of the FACs on the n-th floor accordingly on the weight and volume criteria; Q_W – the rated load of freight elevator, N; Q_V – the nominal volume capacity of the freight elevator, m^3; L_W – the weiht of the trolley, N; L_V – the volume, occupied the trolley, m^3; λ – the number of the trolleys in the freight elevator, pcs; ε – the number of the freight elevators.

The resulting calculated values of the parameters $m_{n.w}$ and $m_{n.v}$ should be rounded to the largest integer value that provides some supply of the FACs production capacity. However, in practice the variant is possible in which due to the high concentration of operations on every FALs is difficult to pick up the rational number of the parallel working assembly equipment taking into account the carrying capacity of the freight elevators. In this case, it is expedient to use FALs with greater differentiation of technological process, which influences the performance of the consistently working assembly equipment.

The condition for achieving the rational performance of the assembly manufacturing

The conditions for achieving the rational performance of multi-floor assembly manufacturing are defined under the following assumptions:

1. The weight (volume) performance of the FACs on each floor is identical and equal $G_{W(V)}$. 2. On each floor there are the same number of the FACs – q (the possibility of layout on the floor of the large number FACs associated with the tendency to reduce the area occupied by them due to the miniaturization of the finished products). 3. Each FAC takes the same manufacturing area of the building and work in parallel. 4. Each freight elevator has the same load W_E (volume capacity VE) and occupies the same manufacturing area of the building. 5. Manufacturing area S of each floor is constant and determined by the following equation:

$$S = q \cdot S_C + \varepsilon \cdot S_E, \tag{8}$$

where: q, ε – accordingly the numbers of the FACs and the freight elevators on a floor, S_C, S_ε – according to the manufacturing areas, occupied a FAC and a freight elevator, m^2.

With the above conditions and equations (1) to (4), (5), (8) are defined the weight (volume) of output products and which are transported by the freight elevators for a cycle of its works on the each floor of the multi-floor assembly manufacturing:

$$\varepsilon Q_{W(V)} = qT_C G_{W(V)} = \frac{2k_O k_C h \cdot F^2 G_{W(V)}(S - \varepsilon S_\varepsilon)}{3600 \nu \varepsilon S_C} =$$

$$= \frac{H F^2 G_{W(V)}(S - \varepsilon S_\varepsilon)}{\varepsilon S_C}, \tag{9}$$

where: $$H = 2k_O k_C h / 3600 \nu. \tag{10}$$

From the quation (9) we will define a rational number of freight elevators of the multi-floor assembly manufacturing:

$$\varepsilon = F\left(\sqrt{b^2F^2 + 4ac} - bF\right) / 2a, \tag{11}$$

where:

$$a = Q_{W(V)} S_C; \quad b = H G_{W(V)} S_\varepsilon; \quad c = H G_{W(V)} S. \tag{12}$$

Taking into account equations (1) and (11), we will define the performance of the multi-floor assembly manufacturing:

$$G_{F.W(V)} = \frac{F G_{W(V)}(S - \varepsilon S_\varepsilon)}{S_C} =$$

$$= \frac{F G_{W(V)}\left(2aS + F^2 b S_\varepsilon - F S_\varepsilon \sqrt{b^2F^2 + 4ac}\right)}{2aS_C} \tag{13}$$

We will find the extrema of the function (13), deciding next equation:

$$\frac{d}{dF} G_{F.W(V)} =$$

$$= \frac{d}{dF}\left[\frac{F G_{W(V)}\left(2aS + F^2 b S_\varepsilon - F S_\varepsilon \sqrt{b^2F^2 + 4ac}\right)}{2aS_C}\right] = 0 \tag{14}$$

After conversion of the equation (14) we obtain the polynomial equation of the sixth degree:

$$AF^6 + BF^4 + CF^2 + D = 0, \tag{15}$$

where:

$$A = 7b^4S_\varepsilon^2; \; B = 64acb^2S_\varepsilon^2 - 36ab^2cS_\varepsilon^2 - 12ab^3SS_\varepsilon; \tag{16}$$

$$C = 64a^2c^2S_\varepsilon^2 - 48a^2bcSS_\varepsilon - 4a^2b^2S^2; \; D = -16a^3cS^2; \tag{17}$$

The equation (15) can be decided in a general form or a numeral method in the chosen intervals of values. The real roots of the equation are determined the extrema values of parameter F, from that we choose the rational number of floors of the multi-floor nanufacturing from of the conditions for its highest performance and the possibility of the building design realization.

Conclusion

The proposed ways of improving logistics of multi-floor assembly manufacturing allow:

1. The efficiency of assembly manufacturing to be increased at the expense of the rational organization of technological streams, providing of rhythmic works of

the FACs, the trolleys application for the transportation of components, finished products and wastes.

2. The rational performance of the FACs during their consistently-parallel work, number in parallel working FACs taking into account distribution of the weight or volume of the finished products on floors and carrying capacity of the freight elevators to be defined.
3. The rational number of the freight elevators depending on their technical characteristics and operating conditions of the multi-floor assembly manufacturing to be determined.
4. The conditions for achieving the rational performance of multi-floor assembly manufacturing to be found, that in turn allows to define the rational number of floors taking into account the height and floor area of the floor, the performance and footprint of the FACs, the technical characteristics of the freight elevators and the area occupied by them.

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Źródło finansowania: Badania statutowe Wydziału Inżynieryjno-Ekonomicznego Transportu, Akademii Morskiej w Szczecinie