SCIENTIFIC
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The role of robotisation in improving bakery product quality

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Keywords: quality of bread, robotisation, reliability

ABSTRACT:

The article aims to present the role of robotisation in increasing bakery product quality, as it is closely linked to machine reliability, as well as hygienic and sanitary conditions. All machines employed in the production process ought to be maintained at full production potential and reliability, which also has a fundamental influence on the final product's quality.
While participating in the 2014-2020 Smart Growth Operational Programme in a bakery, the author isolated factors influencing bakery product quality within the context of production line robotisation. He grouped the factors into three categories present within the production process, i.e., related to raw materials, technological processes, and organisational-technical aspects.

Rola robotyzacji w podwyższaniu jakości pieczywa w branży piekarniczej

Słowa kluczowe: jakość pieczywa, robotyzacja, niezawodność

STRESZCZENIE:

Celem artykułu jest przedstawienie roli robotyzacji w podwyższaniu jakości pieczywa. Ma ona ścisły związek z niezawodnością pracy maszyn i warunkami higieniczno-sanitarnymi, maszyny do produkcji pieczywa powinny być bowiem utrzymywane w pełnej sprawności technicznej i niezawodnościowej, co także wpływa zasadniczo na jakość wypieków.
Autor, uczestnicząc w Programie Operacyjnym Inteligentny Rozwój 2014-2020 w jednej z piekarń wyodrębnił czynniki, które mają wpływ na jakość pieczywa w branży piekarniczej w kontekście robotyzacji linii produkcyjnej i dokonał ich podziału na trzy grupy funkcjonujące w procesie wytwórczym, tj. czynniki surowcowe, czynniki związane z procesem technologicznym oraz czynniki organizacyjno-techniczne.

1. INTRODUCTION

Due to its mainly local nature, the bakery industry constitutes an integral part of a region's forces determining its development. The aforementioned local market is, after all, the main source of raw materials for bakery companies, as well as the main market for their products. Bread is a basic component of every Pole's diet, which, with a rational approach, can play an invaluable role in regulating the human digestive tract and constitute a significant source of the body's daily energy requirements (approx. 25-30%)[1]. Bread (bread and buns) was, is, and will probably for a long time remain a product of key nutritional importance in Poland.

While the change in living standards resulting from economic development has, of course, a positive dimension, it is sometimes perceived as a contributing factor for many diseases. Inappropriate eating habits are seen as the causes of obesity, hypertension, heart disease or diabetes. Awareness of irrational nutrition influences society's expectations towards food producers.

The bakery industry is defined as a set of bakery enterprises offering bread [2]. It constitutes an integral part of a region's forces determining its development, while maintaining a mainly local nature. The aforementioned market is, after all, the main source of raw materials for bakery companies, as well as the main market for their products.

Society's increased requirements regarding bread quality have engendered a need for new system solutions, in which quality becomes a strategic objective.

Bread quality is determined by a certain set of features:

1. Nutritional value – determined by the general chemical composition,
2. Taste – depending mainly on the composition and the quality of raw materials,
3. Health – defined as a lack of risks to consumer health,
4. Attractiveness – determined by the shape, colour and packaging,
5. Shelf life – ensuring shelf life without quality changes,
6. Freshness – equated with the bread's suppleness, smell and taste [3, 4].

2. FACTORS THAT INFLUENCE BREAD QUALITY

The author, during his participation in the Intelligent Development Operational Programme 2014-2020, for the National Centre for Research and Development (NCBiR), as the R&D manager on a project entitled "R&D work on the development of an innovative robotic line for bakery and confectionery production", distinguished factors impacting the quality of bread in the baking industry in his research [5]. These factors have been divided into three groups functioning in the production process, and further into subgroups, which is shown in this list:

I. Raw material factors group, including:
1. Quality of the raw materials used for production.
2. Correctly established bread efficiency standards.
3. Recipes / raw material composition /.

II. Factors related to the process, i.e.:
1. Selection and stability of optimal process parameters.
2. Controlled process efficiency, including:
- control of individual production process phases,
- inter-operational control of the quality of semi-finished products.

III. Organisational and technical factors, including:
1. Hygienic and sanitary conditions.
2. Functionality and reliability of production machines.
3. Technical progress / robotisation /.

The list shows that technical progress, which also includes growing robotisation, is one of the factors influencing the quality of bread. Although it does not affect its quality directly, unlike the raw materials used for production or recipes, but without all the factors distinguished by the author, the bread's final quality would not meet the requirements set by consumers. Employing appropriate quality-oriented measures over the entire production is the only activity guaranteeing that the intended goal is achieved [6].

Literature on the subject does not include studies on the role of robotisation in improving baking quality. Only a few articles describing the influence of factors from the raw material group on the quality of bread can be found. This led to the author's interest in the presented topic.

3. INFLUENCE OF ROBOTISATION ON IMPROVED BREAD QUALITY

Robotisation consists in the introduction of robotic manipulators and associated devices (e.g. feeders, pallets) to the production process in order to perform operations with limited or no human participation [9, 10]. Indeed, the bakery industry faces employee shortages, which is why robotisation is one of the most effective methods of increasing production process efficiency in modern bakeries. Robotisation is tantamount to repeatability, accuracy, as well as significantly increased process efficiency, which all greatly affect the quality of bread delivered to the market. Robots are becoming easier to use and also relatively cheaper despite more extensive equipment. Food producers are increasingly aware that robots do not get tired, are careful and accurate, and do not get bored, nor irritated when performing monotonous production line activities. In the food industry, robots are most often used for handling food products (directly or in packaging) and for palletising [11]. Other advantages of robotisation, such as the fact that it makes the manufacturing process more flexible, increases the standard and quality of foodstuffs, and improves work safety, are also recognised In Europe [12].

The development of robotisation allows a bakery worker to be replaced in monotonous work that requires a lot of physical effort and such performed in difficult environmental conditions, which significantly reduces the scope for errors. Installation of robots in bakeries also leads to improved hygiene standards, which reduces the poisoning risk among customers due to the consumption of products of inadequate quality. In addition, robots reduce dust present in bakery premises. This is important, as the combination of flour dust, high air humidity and temperature creates conditions for the development of microorganisms (mould spores) and pests, such as cockroaches, weevils, mites and moths.

Hygienic and sanitary conditions in bakeries are of significant importance, as they are related to ensuring health safety. They pertain, in particular, to machines, devices, employees and rooms. Health safety is now a requirement within the legal framework [13]. Producing good quality bread requires conditions that meet certain hygienic standards, which is further facilitated by robotisation.

The author, when participating in the Intelligent Development Operational Programme 2014-2020 in the examined bakery X, designed, among others, the layout of a robotic production system based on a multi-tasking industrial robot ROB1 with a KON1 controller used in innovative processes that significantly improve bread quality (see Figure 1). The presented layout diagram for the robotic production system based on the ROB1 robot with the KON1 controller in bakery X was intended to perform the following tasks:

a) feeding trays for arranging dough pieces,

b) feeding trays with baked products for unloading onto a conveyor,

c) decorating bread and special functions (sprinkling grains, cutting dough pieces, applying sauces),

and also contribute to a significant improvement in bread quality within the scope of:

a) attractiveness – by cutting regular dough pieces, which affects the bread's shape,

b) taste – by sprinkling dough with various additions (mainly grains) improving the taste,

c) health – by meeting specified hygiene standards,

d) freshness – by increasing the technical efficiency of production lines.

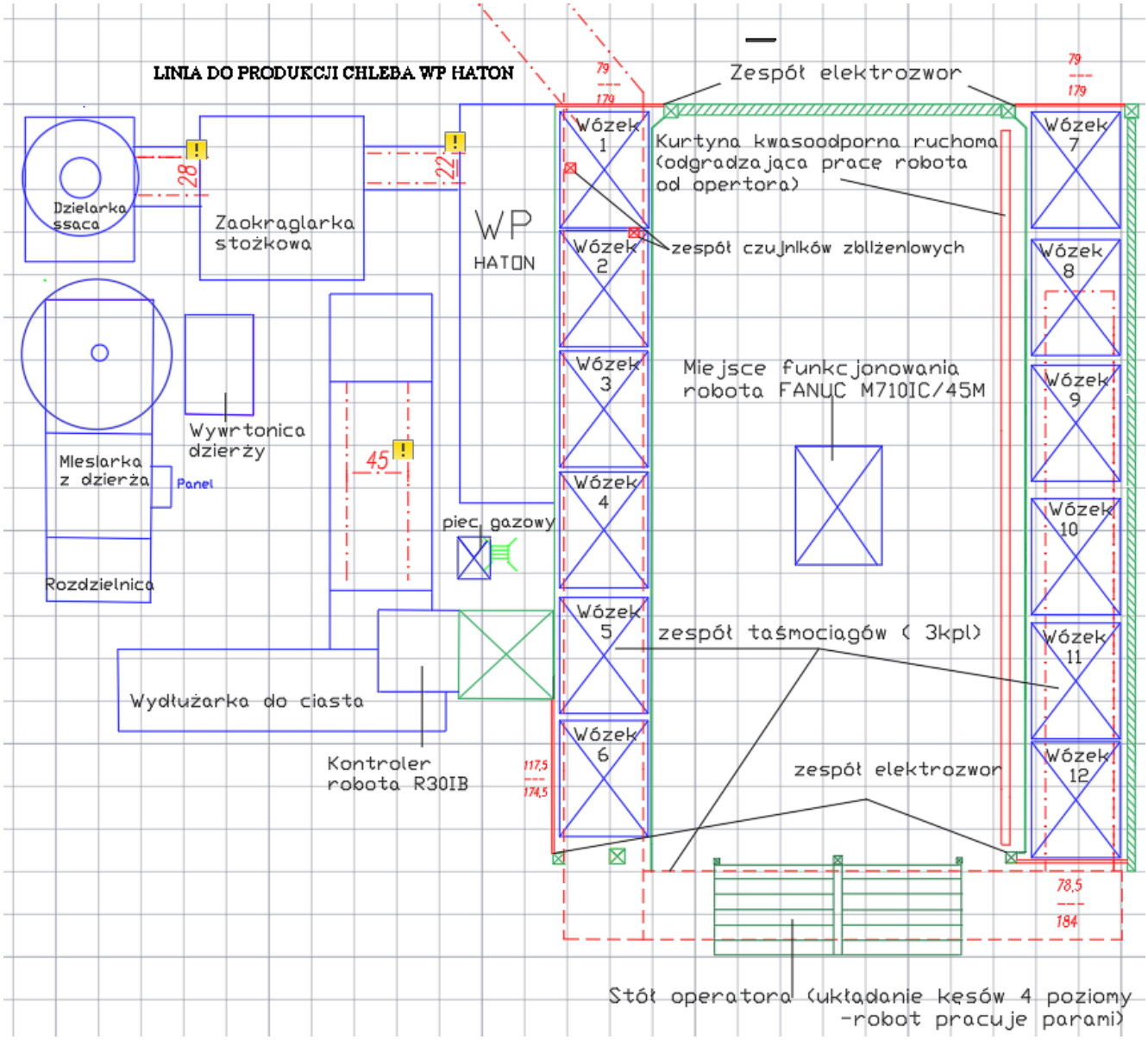

Figure 1 Layout diagram of a robotic production system based on a ROB1 robot with a KON1 controller in bakery X (Source: Own work based on research performed in a bakery)

4. RELIABILITY OF PRODUCTION MACHINES VERSUS BREAD QUALITY

Bread quality is a complex system difficult to easily define. It consists of a set of features, among which freshness is the most appreciated by the customer. To provide consumers with fresh bread, the product is delivered daily. Therefore, bread making machines need to be kept fully operational and reliable.

Further in the article examples of reliability test results of the industrial robot ROB1 with the KON1 controller for production support processes, having key importance for the improvement of bread quality (see Table 1), have been presented.

Table 1 Listing of information on the functioning of the ROB1 robot with the KON1 controller. (Source: Own work based on research performed in bakery X)

Charakterystyka robota ROB1 wraz z kontrolerem KON1	**Parametry dotyczące funkcjonowania robota z kontrolerem**
Czas pracy dzienny	7h
Czas pracy roczny w 2020 r.	7h*312dni = 2184h
Lista zdiagnozowanych uszkodzeń zespołu	*Ogólny czas niesprawności maszyny(lata)*
1. Podczas wprowadzenia przez operatora wózków do gniazda są one błędnie wypoziomowane, co powoduje błędną synchronizację ich pozycji dla robota.	2018 (12x1 dzień - 12x0,5godziny),
	2019 (8x1 dzień - 8x0,5godziny),
	2020 (6x1 dzień - 6x0,5godziny),
2. Podczas wprowadzenia przez operatora wózków do gniazda tace są błędnie wypoziomowane, co powoduje błędną synchronizację ich pozycji dla robota.	2018 (4x1 dzień - 4x0,5godziny),
	2019 (4x1 dzień - 4x0,5godziny),
	2020 (3x1 dzień - 3x0,5godziny),
3. Nieautoryzowane wejście operatora w strefę pracy robota.	2018 (3x1 dzień - 3x0,5godziny),
	2019 (1x1 dzień - 1x0,5godziny),
	2020 (1x1 dzień - 1x0,5godziny),
4. Brak zasilania energii powoduje zatrzymanie pracy robota a po włączeniu zasilania robot wraca do pozycji 0 (strata czasowa)	2018 (2x1 dzień - 2x0,5godziny),
	2019 (2x1 dzień - 2x0,5godziny),
	2020 (2x1 dzień - 2x0,5godziny),
5. Brak zasilania energii powoduje u robota zagubienie synchronizacji pozycji na enkoderze.	2018 (6x1 dzień - 6x0,5godziny),
6. Robot wychodzi poza swoją wyznaczoną strefę pracy (zagrożenie życia operatora).	2018 (6x1 dzień - 6x0,5godziny),
7. Możliwość zatarcia serwonapędu w robocie spowodowane ponadnormatywnym udźwigiem	2018 (2x1 dzień - 2x4godziny),
	2019 (2x1 dzień - 2x1godzina),
	2020 (2x1 dzień - 2x1godzina),
8. Przeciążenie układu spowodowane podwyższoną temperaturą pracy robota	2018 (2x1 dzień - 2x1godzina).
Rok zakupu maszyny	2017
Symbol w procesie	RK_T
Czas bezawaryjnej pracy	3 lat = 6508h
Zakładany czas bezawaryjnej pracy	3 lat = 20000 godzin

Calculations of the expected failure-free uptime for the ROB1 robot with the KON1 controller are presented below, calculated for exponential distribution according to the formula:

$$R(t) = e^{-\lambda t}$$

where:
t – current failure-free uptime of the assembly
E(t) – estimated time of failure-free operation of the assembly
R (t) – reliability function presented as the probability of the unit's operation in accordance with its intended purpose in a given period

$$E(t) = \frac{1}{\lambda} \text{ [godz.] , gdzie } \lambda = \frac{1}{20000} = 0{,}00005$$

$$R(t) = e^{-\lambda t} = e^{-0{,}00005*6508} \approx 0{,}7222$$

For the exponential distribution of the reliability function, the R(t) estimated failure-free operation time of the ROB1 robot with KON1 controller is 72.22%.
The Weibull distribution was prepared for the p = 1, p = 2, p = 3 indices using the formula

$$R(t) = e^{-\left\{\frac{t}{a}\right\}^p}$$

to determine the expected failure-free uptime of the ROB1 robot with KON1 controller.

$$p=1 \quad R(t) = e^{-} \left(\frac{6508}{20000}\right)^1 \approx 0{,}7222$$

$$p=2 \quad R(t) = e^{-} \left(\frac{6508}{20000}\right)^2 \approx 0{,}8995$$

$$p=3 \quad R(t) = e^{-} \left(\frac{6508}{20000}\right)^3 \approx 0{,}9661$$

For the Weibull distribution of the reliability function R(t), the estimated failure-free operation time of the ROB1 robot with the KON1 controller is as follows for the indices: p = 1 – 72.22%, p = 2 – 89.95%, p = 3 – 96.61%.
The Gamma distribution was prepared for the indices p = 1, p = 2, p = 3 using the formula

$$E(T) = \frac{p}{b}$$

to determine the expected failure-free uptime of the ROB1 robot with KON1 controller. The reliability function was calculated using the formula R(t) = 1 – F(t).

$$p=1 \qquad 20000 = \frac{1}{b} \qquad b = 0{,}00005$$

$$R(t) = 1 - e^{(-0{,}00005*6508)} * \left[\frac{(0{,}00005*6508)^1}{1}\right] \approx 0{,}7650$$

$$p=2 \qquad 20000 = \frac{2}{b} \qquad b = 0{,}0001$$

$$R(t) = 1 - e^{(-0{,}0001*6508)} * \left[\frac{(0{,}0001*6508)^1}{1} + \frac{(0{,}0001*6508)^2}{2}\right] \approx 0{,}5216$$

$$p=3 \qquad 20000 = \frac{3}{b} \qquad b = 0{,}00015$$

$$R(t) = 1 - e^{(-0{,}00015*6508)} * \left[\frac{(0{,}00015*6508)^1}{1} + \frac{(0{,}00015*6508)^2}{2} + \frac{(0{,}00015*6508)^3}{6}\right] \approx 0{,}3944$$

For the Gamma distribution of the reliability function R(t), the estimated failure-free operation time of the ROB1 robot with the KON1 controller is as follows for the indices: p = 1 – 76.50%, p = 2 – 52.16%, p = 3 – 39.44%.
Figure 2 shows the damage intensity chart for the evaluated multi-tasking industrial robot with a wide motion range ROB1 with a KON1 controller for production support processes in the 2018-2020 period along with a simulation of their operations in the 2021-2025 period.

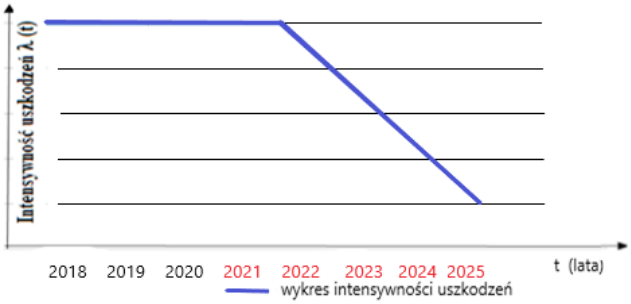

Figure 2 Damage intensity diagram for the ROB1 industrial robot with the KON1 controller in 2018-2025 (Source: Own work based on research performed in bakery X)

5. SUMMARY AND CONCLUSIONS

Bread quality is a complex system difficult to easily define. It consists of a set of 6 features, among which freshness is the most appreciated by the customer. In order to provide customers with high-quality bread, the machines used for its production should always be in good technical order and reliable.
Robotisation is closely linked to hygienic and sanitary conditions, but these apply not only to machines and devices, but also to employees and

premises. Robots in bakeries also reduce dust in the rooms. Flour dust combined with high humidity and air temperature creates conditions conducive to the development of microorganisms and pests.

The development of robotisation allows a bakery worker to be replaced in monotonous work that requires a lot of physical effort and work performed in difficult environmental conditions, which significantly reduces the scope for errors. For example, the introduction of robots to production lines in bakery X improved bread quality in the following areas:

- attractiveness – by cutting regular dough pieces, which affects the bread's shape,
- taste – by sprinkling dough with various additions (mainly grains) improving the taste,
- health – by meeting specified hygiene standards,
- freshness – by increasing the technical efficiency of production lines.

It also needs to be underlined that robots do not get tired, nor bored, nor irritated, they are diligent and accurate in performing monotonous production line work. In addition, they do not pose a disease risk, which is important in the food industry. Robotisation in bakeries means reliability, operational precision and significantly increased process efficiency, which significantly affects the quantity and quality of bread delivered to the market. This article is addressed to baking industry entities that intend to introduce robotisation. It includes indications of possible increases in suitability and effectiveness of machines thanks to robotisation, and also makes it possible to get acquainted with the author's findings regarding the impact of robotisation on raising bread quality.

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