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OPTIMIZATION OF FOIL CONSUMPTION FOR PACKING DEEP FROZEN FRUIT
OPTIMIZACIJA UTROŠKA FOLIJE PRI PAKOVANJU DUBOKO ZAMRZNUTOG VOĆA

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ABSTRACT

In the case of packing deep frozen fruit in PVC foil, the foil consumption is significant and it is calculated per unit of mass or per unit of length. The measurement of foil consumption can become inaccurate because there are many technological and technical problems. The optimization of solutions for foil consumption is based on the application of encoders on existing packing machines and it is the key for obtaining correct results. This paper shows a model of a foil consumption measuring system, which helps provide a lower price for packing.

Key words: *frozen fruit, packing, foil, encoder, optimization.*

REZIME

Pri pakovanju duboko zamrznutog voća u PVC folije potrošnja folije je velika i računa se po jedinici mase ili po jedinici dužine. Merenje utroška folije podleže gršci usled brojnih tehnološko – tehničkih problema. Optimizacija rešenja za utrošak folije je bazirana na implementaciji enkodera na postojećim mašinama za pakovanje i ključna je za dobijanje relevantnih rezultata. U radu prikazan je novi model mernog sistema utroška folije koji obezbeđuje niže cene pakovanja.

Ključne reči: *zamrznuto voće, pakovanje, folija, enkoder, optimizacija.*

INTRODUCTION

The process of packing frozen fruit starts with assembling cardboard boxes through warm gluing, continues with cutting PVC foil, manufacturing and inserting bags into boxes, and in the following step these are ejected and transported to the scales where they are filled up. This part of the process is shown in figure 1. The scale measures the necessary amount of fruit that is tranported to the bags through a segmented belt conveyer with shovels and a vibrating dosage device. After deep frozen fruit reaches the previously created bags, over a transport system the fruit is transported to a machine for closing PVC bags and a machine for closing cardboard boxes by gluing. After that, through a transporter for cardboard boxes, these boxes reach a metal detector with rejection system and control scales with rejection system, and at the end of the packing process also to the cardboard box transporter with printing device (*Jovanović 2007*).

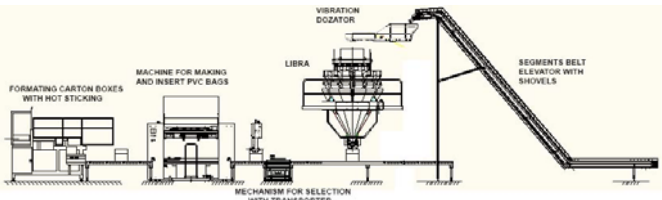

Fig. 1. Part of packing line for deep frozen fruit (Marković, 2008)

The amount of foil, necessary for packing the finished product is being corrected based on empirical data concerning possible rejection. The mass of foil necessary for one package is determined empirically and may differ from delivery to delivery. Therefore it is necessary to perform an inspection of the foil ordered. The prepared foil samples for one product type, are measured one by one on a precision scale and thus the mass of each sample is determined. Based on the results obtained, a medium value (arithmetic medium value) for all samples is determined and that value represents a basic measure for this type of foil for a corresponding delivery. The mass of samples has to meet the prescribed tolerances, and if they do not, it is determined which part of the delivery has not met a criterion and that one is returned to the supplier (*Lazić at al., 2008, Marković, 2007*):

$$m_e = \frac{\sum_{i=1}^{n} m_{ui}}{n} \quad (1)$$

where: m_u – is the mass of a sample, m_e – the basic measure of mass for a corresponding product from the delivery, n – the number of samples for the corresponding product.

The cause for rejection and its amount is almost impossible to foresee and control. Because the market price of foil is very high, uncontrolled occurrence of rejection can seriously affect production loss. Therefore it is necessary to introduce an internal inspection procedure of the supplied foil. The data obtained during inspection are later used for establishing a production plan. This inspection is important both from the aspect of faultlessness of foil and also its features that have to be within the given limits, so as to prevent the quality of packaged frozen fruit to deteriorate during transport and storage.

Analysing the existing foil measuring and recording system, we have come to the conclusion that it is necessary to upgrade the existing system both in sense of hardware and software. The assessed deficits of the existing foil consumption measuring and recording system are as follows (*Gvozdenović and Lazić, 2008*):

1. The system cannot measure the total amount (length) of foil which passes through the packing machine.

2. Foil is usually purchased by mass units. That requires converting the number of bags needed for packing a certain amount of coffee, into kilograms of foil required, using the data for the basic measure which has been defined based on the previous delivery of foil.

3. The incompliance of the data in the records exists because the primary rejection is registered as a number of bags, but the secondary rejection is expressed in kilograms. The recording procedure is special for every type of foil (type of product)

which additionally complicates the procedure of recording and processing data.

4. The rejection data, expressed in kilograms, depend on the basic measure data for the respective type of foil. The basic measure data are obtained empirically and are subject to errors.

5. Enables the operators to manipulate the data regarding primary and secondary rejection.

6. The impossibility to control the accurracy of foil length data on the roll, provided by the manufacturer. This is because it is not possible to accurately measure the lenght of foil which has passed through the machine.

7. The database does not exist in electronic form.

To determine the amount of used foil more accurately, it is necessary to upgrade the system in terms of hardware. For the collected measurement and control data to be digitalised and in an appropriate form made available for viewing and processing, the system needs to be improved in terms of software. In real situations, the occurrence of secondary rejection is rare, and when it happens, it is detected easily, and in most cases the cause is an error on the side of the supplier. Therefore, greater attention has been paid to solving the problem of measuring and recording primary rejection, which occurs during packing of products. Adopted was a solution that is based on the measurment of foil using an optical encoder, where the processing of the encoder impulse and the associated logic are performed by means of a programable logical controller. Since the measuring system should depend on the machine as little as possible, the possibility to use the already existing encoder located above the foil-pulling belts, was not taken into account. Very important assumptions have been made, as follows:

Assumption 1: The measuring wheel of the encoder rolls over the foil without sliding.

Assumption 2: Tension of the foil due to stress is neglected.

Assumption 3: Temperature-based dilatations of foil are neglected. The manufacturing rulebook states that the roll has to stay in the packing facility at least 6 hours after it was brought in from the storage facility, before it is used.

Assumption 4: Temperature-based dilatations of the measuring wheel of the encoder do not affect the measuring error.

MATERIAL AND METHOD

In this project, the following components were used:

- encoder with a resolution of 1000 impulses per rotation;
- an encoder bracket which has been custom designed;
- an electromechanical, stable, normally closed, switch;
- a PLC controller EUROICC, with 8 analog inputs and output terminals, each;

Every encoder has a measuring wheel made of aluminium, with an external cylindrical surface rubber coat, in order to obtain better adhesion to the foil. The mounting position of the encoder should be chosen very careful. Three major factors influencing the encoder mounting position, are:

1. calm flow of foil, so that the measuring error caused by the sliding of the encoder's measuring wheel can be neglected (compliant with assumption No. 1)

2. minimum tensile force, because the measuring error due to tension of foil (comliant with assumnption No.2) has been neglected and

3. unhindered work of the operator.

According to the above mentioned conditions and the assumptions made, the optimum position is at the unwinding roll itself. In that position, there is no tensile force, but due to the complexity of the mechanism needed, this option was ruled out. At a later stage of system upgrading this should be taken into account. An encoder bracket that through its kinematics enables unhindered drawing of the foil through a system of rollers, was designed and with its dynamics it secures the adhesion of the measuring wheel to the foil. Adhesion is achieved by a force small enough not to damage the encoder, but big enough to generate rolling without sliding. Switch and bracket of the encoder are located on top of the construction of the foil guidance system, figure 2. The switch is connected so that it is normally closed and is set up so that when the roll is mounted onto the machine, the shaft of the roll pressures the wheel of the switch and thus disconnects the power circuit. When the shaft is lifted again, the switch becomes active again. In this way, we obtain information whether the foil roll has been placed on its bracket and whether it is necessary to measure the length of the foil used. An aluminium measuring wheel, which on its periphery is rubber coated, is secured to the axle of the encoder. The encoder is fixed to the bracket by means of a spring.

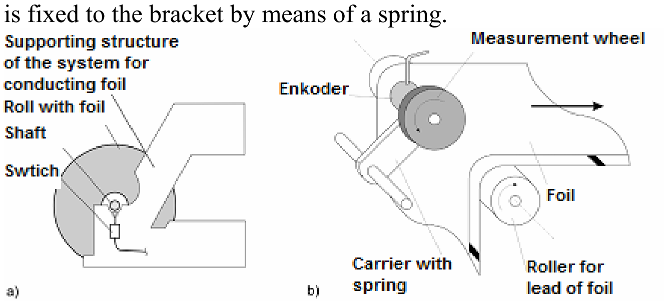

Fig. 2. Positional sheme a) switch and b) encoder on the machine (Gvozdenović and Lazić, 2008)

As the foil moves through the machine, the measuring wheel of the encoder rolls over the foil without sliding and turns the axle of the encoder. The encoder emits impulses through the input channels of the controller to an appropriate hardware counter, figure 3. The counter counts these impulses and stores the number in its internal register of current values, CV. When the current number of impulses in the CV register becomes equal to the programmed number of impulses in register PV, the counter sends an interrupt to the processing unit, resets the value in register CV and starts counting from zero again. The subroutine that was called by an interrupt, increases the value of the corresponding register by 1. That means, that the value in the PV register of the counter in fact is equal to the number of impulses counted for one reference length. Out of practical reasons, the reference length was chosen to be one meter. The approximate number of impulses for one meter was obtained by caluculation, but it is corrected during calibration.

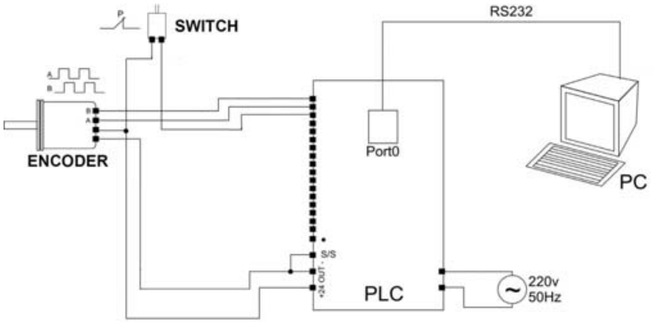

Fig. 3. Scheme of measurment equipment for measuring foil consumption (Đekić and Marković, 2006)

RESULTS AND DISCUSSION

An acceptable leve of inaccurracy for a new independent system for measuring foil consumption should be less than 0.1%. If we, for example, assume that the length of foil on the roll is approx. 1500 m, that would mean that the measuring error for that roll should be less than 1.5 m. Due to the design of the encoder, the diameter of the wheel on the axle of the encoder has to be greater than 44 mm, and because of the limited space on the construction of the foil feeding system, a maximum measuring wheel diameter of approximately 100 mm is recommended. One should take into account that the possibility to design and manufacture any kind of transmission was ruled out.

$D_t \approx 44 \div 100$ mm

For an encoder with a resolution of 1000 imp./rev. we get a length that corresponds to one encoder impulse:

$$L_{imp} = \frac{O_t}{1000} \tag{2}$$

where: O_t is the circumference of the encoder wheel, which is obtained by multiplying the diameter with the number.

Due to a certain level of inaccuracy in manufacturing of measuring wheels and the elastic deformations of the rubber surface, with which it adheres to the foil, it is obvious that the value for $L_{imp,}$ obtained in such a way, is not absolutely accurate. If we assume that the diameter error due to inaccurate manufacturing and elastic deformation is ±0.1mm, we can calculate the error for one roll:

$$L_{imp} = \frac{O_{t1}}{1000} \tag{3}$$

where: L_{imp1} – is the actual length per one impulse, O_{t1} is the actual circumference of the measuring wheel.

The total number of counted impulses is:

$$I_U = \frac{L_{kot}}{L_{imp1}} \tag{4}$$

where: L_{kot} is the actual length of foil on the roll.

The measured length is equal to:

$$L_i = I_u \cdot L_{imp} \tag{5}$$

and the measuring error is:

$$G = L_{kot} - L_i = L_{kot} - I_u \cdot L_{imp} = L_{kot} - \frac{L_{kot}}{L_{imp1}} \cdot L_{imp} = = L_{kot} - \frac{L_{kot}}{\frac{O_{t1}}{1000}} \cdot \frac{O_t}{1000} = L_{kot}(1 - \frac{D_t}{D_t}) \tag{6}$$

where: D_t is the actual diameter of the measuring wheel.

The error as a function of the difference between actual and calculated diameter is shown in figure 4. The error is shown in form of an absolute value, and the actual diameter value was assumed to be D_t = 63 mm. Based on this, we see that it is necessary to enable the calibration of values read from the encoder

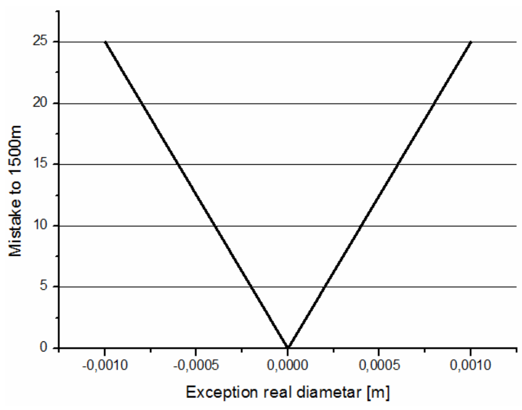

Fig. 4. Diagram of error on 1500 m of measured foil as a function of the deviation of the diameter of the encoder measuring wheel

The reference length L_R is the foil length for which the encoder emits N_R impulses. When the corresponding hardware counter counts N_R impulses, it sends an interrupt to the processing unit, which in turn, executes the appropriate subroutine. With every interrupt, the value of the corresponding register is increased by 1 through the subroutine, and thus the measured length is obtained when you multiply the number of increments by the reference length. This way, the processing unit of the controller is significantly relieved, because the subroutine is executed only when there is an interrupt of the counter. The reference length was assumed to be 1m, and when calculating with a measuring wheel diameter of 63 mm we get the approximate value of 5050 encoder impulses.

If, for example, the value in the PV register of the counter is 5050, and the actual value is 5049, then we would, with every interrupt, i.e. increment of the corresponding register value, have one additional impuls. For a roll of 1500 m, there would be 1500 increments and thus an additional 1500 impulses. Since 5050 impulses correspond to approx. 1m, the error in this case would approximately be: 1500/5050=0.297 m, which is a little less than 0.02% for the whole roll. This means that by correction of N_R to 5049, the system would measure without an error. We should mention that we in this case assumed that L_R = 1 m of foil is possible to represent as an integer number of encoder impulses N_R.

Practically it is not possible to obtain an integer value for $N_{R,}$ and thus the system always measure with a certain error. This error should be minimized by means of calibration. Since on a sample of 1500 m, the deviation of the reference number of impulses from the actual value for 1 impulse yields an measuring error of 0.297 m, that means the system could be set to have a measuring error not greater than +/- 0.297/2, which is less than 0.01%. To obtain a number of impulses for 1m which is approximately equal to the actual value, it is necessary to make a correction to the values in the PV register of the encoder's counter. The problem is to obtain a relevant sample of the foil length on base of which a accurate enough correction of the number N_R can be made. This paper describes the method of how this sample is obtained.

It showed that when the sample is obtained in this way, we get a measuring error of less than 0.1%, and it also showed to be very practical.

The calibration is performed as follows: the packing machine is stopped and the data for $N_M^{'}$, $N_{KP}^{'}$ and $N_i^{'}$ are read.

After that, the machine is left to work until it packs approximately 1000 bags, which approximately corresponds to a length of 200-250 m, depending on the type of package. Then, the machine is stopped again, and the values $N_M^{''}$, $N_{KP}^{''}$ and $N_i^{''}$ are read, where : N_M is the number of bags on the printing display on the machine, a number that corresponds to the number of boxes in which the bags are inserted, and on which the date is printed out, where $N_M^{'}$ is the value at the start, and $N_M^{''}$ is the value at the end of sampling; N_{KP} is the number of bags displayed on the screen of the check-point. This number is equal to the number of properly filled bags, where $N_{KP}^{'}$ is the value at the start, and $N_{KP}^{''}$ is the value at the end; N_i is the number of bags displayed on the status screen of the foil measuring application, measured based on the encoder impulse countdown, where $N_i^{'}$ is the value at the start, and $N_i^{''}$ is the value at the end of sampling.

If, in absolute values, the following applies:

$N_M^{'} - N_M^{''} = N_{KP}^{'} - N_{KP}^{''}$ (7)

that means that all bags with an imprinted date are also correctly filled, i.e. it means that the number of bags which have passed through the packing machine, also passed through a check point which includes metal detecting and weight control devices. This way, we have obtained a relevant sample on base of which we shall correct the number of impulses for the reference length. If this condition is not fulfilled, the sampling should be repeated.

If, for example, in absolute values, the follwing applies:

$N_M' - N_M'' = N_{KP}' - N_{KP}'' = 1004$

$N_i' - N_i'' = 1001$,

then that means that the system has measured a number of bags smaller than the actual one, and therefore N_R should be reduced. Since one impulse of the encoder corresponds to a measured length of 0.198 mm, this means that for 1000 increments, the system makes an error of approximately 198 mm.

If, for example, sampling would be carried out on the roll for packing of sour cherries, that would mean that by decreasing N_R proportionally to the cutting length of foil, the error would be reduced to a minimum. After changing N_R, at least one more sampling should be conducted, in order to obtain optimum measuring results.

It is recommended to perform a correction of reference length every time after removing and mounting the encoder mechanism again. Table 1 shows a form that is filled in at calibration of the system.

Table 1. Form for system calibration

Machine:_________	Measurement Number:____		Date: __________	
	N_M	N_{KP}	N_i	N_R
start (‘)				
stop (‘‘)				
	N_M'-N_M''	N_{KP}'-N_{KP}''	N_i'-N_i''	Corection N_R

CONCLUSION

The technical solution for an independent system for measuring foil consumption on machines for packing frozen food into PVC packaging material described in this project, can be successfully implemented and put into operation. The measured data were satisfying, with an measuring error of less than 0.1%. The method for obtaining a relevant sample of foil length also has proved to be sufficiently accurate and was adopted as a standard procedure in system optimization. If the packing machines already have encoders implemented, the calibration procedure described above can also be used for these machines.

The reference length of one meter has proved to be exceptionally practical, and the correspondiong number of impulses enables optimum operation of the PLC controller. As far as harware is concerned, the design of the encoder bracket should be improved. Another item that should be worked on is the optimization of an additional contactless measuring system, which would serve for automatic calibration of the reference number of impulses.

Further upgrading of the system’s software is also possible. An intuitive interface for the foil measuring application should be developed. The display of the actual packing speed(rate) and the display of alarm messages should be implemented. Upgrading the software could also include developing additional application software, which would enable monitoring the system and generating reports over a local network. Introducing barcode technology could entirely eliminate the input of data concerning foil rolls through the foil measuring application.

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