Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2020, 7(8):133-141

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Control System of Resonance Frequency Sensor as a Part of Recycling Process

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Abstract The reverse logistics is the field which is of a high importance and is based on the technical development in the various fields. Various companies have specific waste for recycling. Our contribution deals with the recycling process in collaboration with the external company in the factory for production of boxes mostly made of corrugated paper. The amount of waste paper in the company is so great that they should press it into pellets before the transportation for recycling into the external company. The designed resonance frequency sensor is used to prevent clogging in the pelleting machine. The process is controlled also via the internet connection. The paper comprises also the mathematical modelling of the process. The modelling uses the least squares as statistical method as well as the differential equations.

Keywords control, resonance frequency sensor, recycling process, reverse logistics, mathematical modeling

Introduction

Promoting environmental health is always of a high importance. So, every economic decision should stay in unity with the environmental aspects. Among the economic viewpoint we recognize important savings in certain materials, recovery of the value in some components and recovery of the value still incorporated in the used sources and products [14]. From the environmental motives, we might name concern regarding scarcity of raw materials, danger connected with pollution with chemicals and the solid waste as well as landfill saturation. Nowadays development is typical also with the increasing level of consumption that brings also more “reuse” opportunities of both used products and materials. The management of new material flow that is opposite to the traditional supply chain means also development new methods and reverse logistics models [13]. Quantitative data and their analysis using the methods of descriptive as well as analytic statistics bring new ideas regarding relations among the values of physical quantities as determinants characterizing the quality of the environment and their interpretation [1]. To set the proper supply chain strategy, the design of logistics model should include corresponding transportation strategies, location of warehouse as well as of the production facilities [10]. Also, qualitative research methodology is appropriate if the research regarding manager activities is innovative or if nobody described the process yet [11].

The reverse logistics system started to appear as important determinant of supply chain performance. The optimal reverse logistics system ensures the unity of both economic and environmental factors. Thus, in addition to manufactured items, the optimal operating costs of production include the costs of remanufactured items. One of the possible expressions of individual dependencies within the supply chain is a quadratic relation. Thus, the objective function means minimizing the sum of quadratic deviation [7]. Because logistics is such an important part of production processes, it is also a thematic area of many scientific projects [9] and means sustainability only in coordination with the reverse logistics initiatives [30].

Reverse logistics is constantly more or less connected with effect of uncertainty. To improve financial flow Markov chain approach to modeling creates the possibilities for retailers [17]. Also, according to a stricter environmental legislation, the risk factors are considered in the models. The mutual dependency of both manufacturers and customers is essential to influence the success of unity in remanufacturing efforts and the law of environmental protection as remanufacturing requires that used products are obtained with the company from the user. Both forward flow of goods from the manufacturer to the consumer as well as vice versa the flow from customer for remanufacturing include activities supporting with the information technologies [19], such as for instance the shipping details. The queueing model added some dynamic aspects such as inventory location and lead time, using the integer nonlinear programs [23]. Hybrid remanufacturing, when manufacturer chooses the remanufacturing partner, makes easier to optimize the remanufacturing cost [24]. From this point of view a supply chain means also management initiatives of collaboration and information sharing among manufacturers, customers, distributors, suppliers and retailers working together not only to convert raw materials to products but also in recycling processes [27]. Acquisition is the way to get the used product from the customer [29]. Various incentive policies make the customers to collaborate such as for instance cash for product return, deposits, so called scrappage, which means better price for a new product or a replacement purchase.

The stochastic approach with integer linear programming can examine economic relations of distribution centers, suppliers and facilities. However, some deterministic elements are possible while taking the risk factors into account [8]. Optimization models for selection of third-party reverse logistics provider uses the method of imprecise data envelopment analysis. However, the manufacturers as decision makers must carefully identify appropriate inputs and outputs measures to be used in the decision-making process [32]. One of the possibilities to measure the degree of implementation of circular economy is the scale [26], which expresses the levels of implementation as graphical representation of the following determinants with the direct impact to environmental issues: transition to circular economy, emissions, materials, efficient management of energy, waste management, water management and so called 3Rs: reduce, reuse, recycle. The reverse flow is expressed also through the facility location model [25].

Using the content analysis method for literature review as a part of observational research shows that the recent remanufacturing researchers focus mostly on product types such as refillable containers, mobile phones, cellular telephones, single-use cameras, automobiles, especially automotive parts, toner cartridges, jet engine components and photocopiers [18]. In many cases general applicability of the model is discussed [21]. The tendency to generalize the research results reveals specifics of reverse logistics performance in small comparing to large companies [31].

Our contribution in the research activities focuses to reverse logistics system in the packaging industry. As the company produces boxes made of the corrugated paper, the paper material as waste is in so amount, that it should be pelleted for easier transportation into the external company for the recycling process. The resonance frequency sensor prevents clogging of the pelletizer. As the control requires constant control, the situation in the pelletizer chamber is monitored from the office via an Internet connection. Remote control is also necessary to prevent the pelletizer from becoming clogged even when employees are going to eat during the lunch break. If the pelletizer becomes clogged, the supply pipes are also clogged, which means several shifts in the disassembly of the device and subsequent cleaning from clogging.

Incorporation of the Resonance Frequency Sensor into the System of Recycling Processes in the Company

To keep the production process not only effective but also environmentally friendly, the supply chain of supporting activities such as reverse logistics and repair services should also show their profitability. So, optimizing the production costs mean also considering the logistics as well as the inventory costs. The logistics costs include especially costs for transportation, order processing including lot quantity costs, warehousing and inventory carrying costs. Designing the reverse logistics cycle must also cope with another several problems. The research in the construction organizations in South Australia shows that for instance usage of salvaged materials is often of higher cost than production from new materials [6]. Therefore, the recycling process comprising the materials such as water, electronics, metal, plastics and paper, including the possible repair and reuse of the materials [3], should be included in the company's logistics system to represent optimal operating costs. Reverse distribution channels in general do not occur as cost effective in all industries and therefore government ecological environmental legislation and intervention are necessary [33]. Several supply chain models analyze also the minimal operating costs in implemented specific reverse logistics systems in Brazil, China [4], Netherlands [5], European steel industry [28], Malaysian E&E Companies [20] and Asia in general [12].

Figure 1 illustrates the reverse logistics system as included into the production process. The schematic representation is based on designing the system of the recycling processes in the company for production the boxes as packaging made of the corrugated paper. Every part of the described process means some extra costs for the company. Dirty used water is recycled directly in the company with the specific equipment. Only foam, as concentrated dirt, is transported with the external company. Metal recycling is managed with the external company including the transportation. However, the company of the box production has the costs related to disassembly and collecting the metal material. Plastic material is collected in the containers for transportation with the external company and does not mean extra cost except of the storage space.

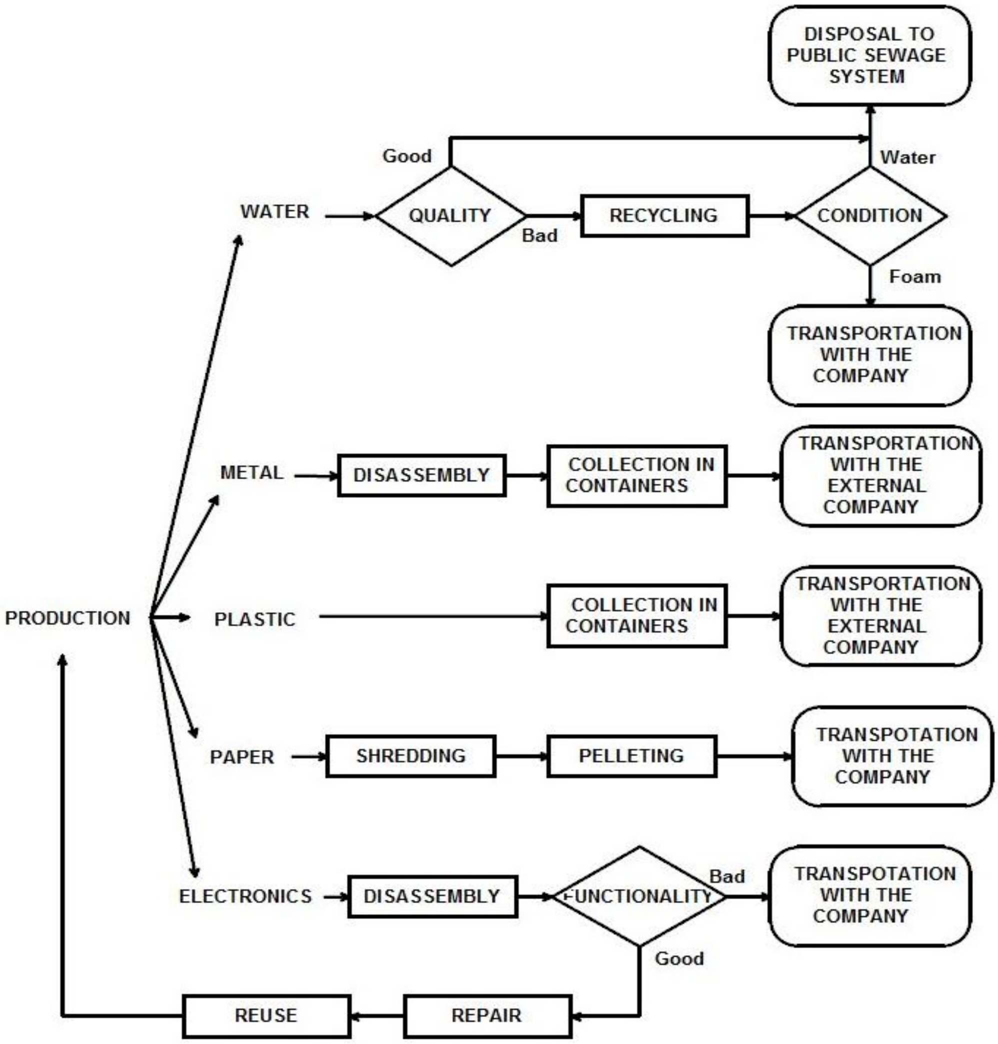


Figure 1: The schematic representation of reverse logistics system as included into the production process

E-waste from electronic and electrical equipment started to become of serious concern not only for its increase but also for the hazardous substances contained in them. In developing countries, the legislation tries to concentrate recycling activities into the formal sector to ensure proper equipment and training to avoid negative effects. General e-waste reverse logistics model comprises activities where e-waste is generated, collected, treated and used as recovered material. The linear programming model has proved particularly useful for expressing costs with individual activities [22]. Our suggested model consists of the phases of disassembling the electronic equipment and the following decision regarding the functionality of the individual components. If it is possible to reuse the device or components, repair and reuse are performed. Otherwise, the material is transported to a company that specializes in recycling.

The paper is shredded directly in the production hall and is transported in pieces of size approximately 2x6 centimeters through the pipes to the pelleting machine in the collection yard. In the pelleting machine, the paper is collected in the chamber for the following pelleting into the boxes in the shape of prisms. If paper accumulates in the chamber during transport and a blockage occurs, a large part of the machine, including the feed pipes, must be disassembled and cleaned. In the pelleting machine, the paper is collected in the chamber for the following pelleting into the boxes in the shape of prisms. If paper accumulates in the chamber during transport and a blockage occurs, a large part of the machine, including the feed pipes, must be disassembled and cleaned. Therefore, the frequency resonance sensor is placed, as it is expressed in Figure 3. The way, how the sensor works, is described using the flowchart diagram in Figure 2. The processing of waste paper to the blocks in the shape of prisms for subsequent transport to an external company is part of the reverse logistics system.

Vast range of scientific publications focused to modelling the reverse logistics problems [15] on different levels of managerial decision-making, convex optimization, nonlinear programming and forecasting methods. Specific modifications are based on both deterministic and stochastic approaches. To optimize strategies for the acquisition of the components as well as materials based on the product assessment process [16] can greatly help the product revaluation.

The binary [2] linear programming model can be used to optimize the costs included in the repair supply chain the following way:

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} \qquad (1)$$

where

m … the number of repairs,

n … the number of potential service crew domiciles,

x_{ij} … binary decision variable.

$$x_{ij} = \begin{cases} 1 \; if \; repair \; i \; is \; assigned \; to \; service \; crew \; domicile \; j \\ 0 \; otherwise \end{cases}$$

for $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$

while

$$\sum_{j=1}^{n} x_{ij} \geq 1 \qquad (2)$$

for each $i = 1, 2, \dots, m$.

Any processing of materials within the reverse system, sometimes including transport to an external company for further processing, means extra costs for the company, which are many times higher than the profit from recycled materials. Therefore, cost optimization within recycling processes is an important part of the firm economy.

Methodology

The resonance frequency sensor is mounted on the wall of the working chamber as a part of the pelleting machine as it is expressed in Figure 3. The chamber is usually full of paper pieces which are falling to another part of the machine for the pelleting into prisms of optional size. As the papers are falling in the working chamber, they strike the rod, which is a part of the resonance frequency sensor. A magnet and an electronic part are mounted on the outer part of the rod, which senses the movements of the rod.

At the beginning of the process, a 0.25V voltage oscillation is excited on the rod by Schottky diodes (Figure 5). If the chamber becomes clogged, the vibration of the rod is damped. The process is expressed in Figure 2 as the flowchart diagram. The process is monitored via the Internet connection (Figure 5).

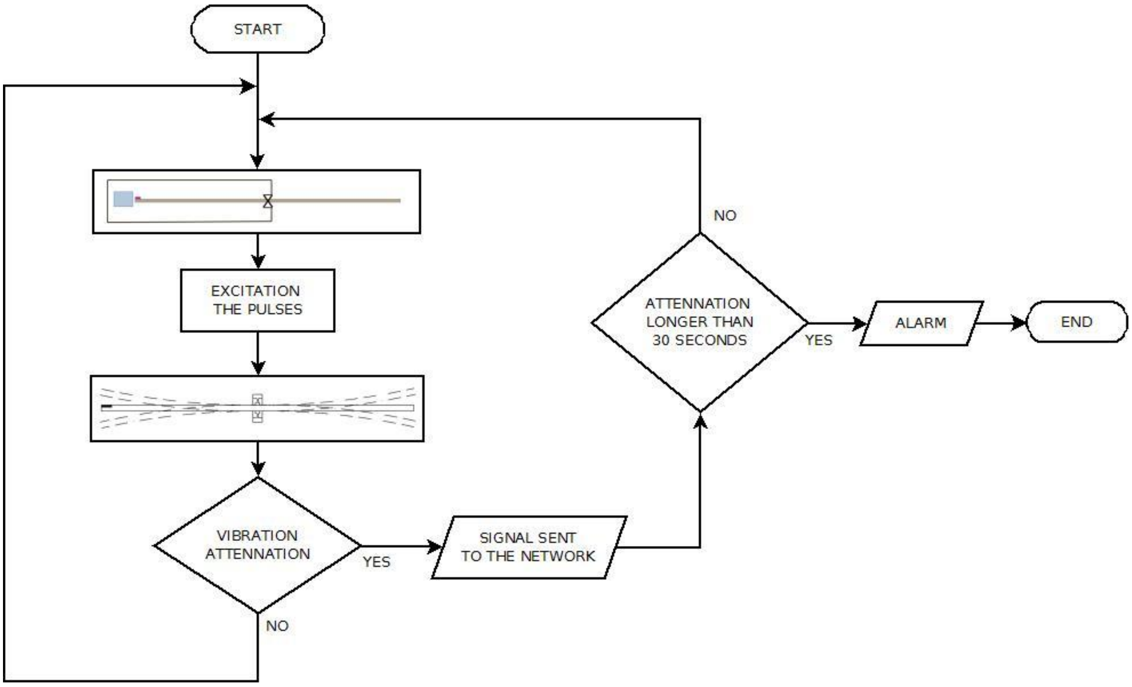


Figure 2: The principle of resonance frequency sensor expressed using the flowchart diagram

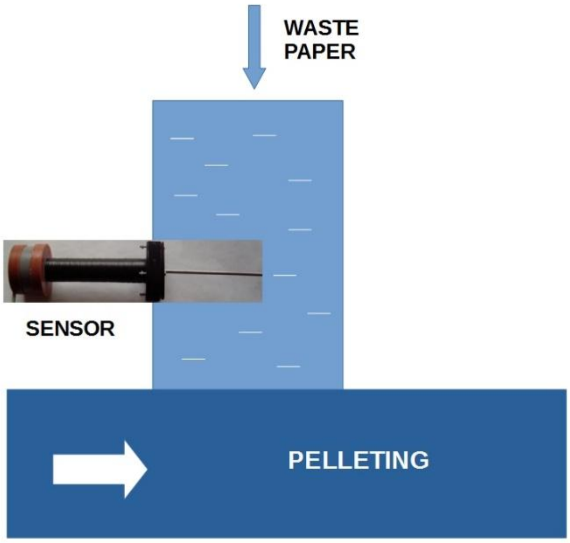


Figure 3: The pelleting process with the working chamber where resonance frequency sensor is placed

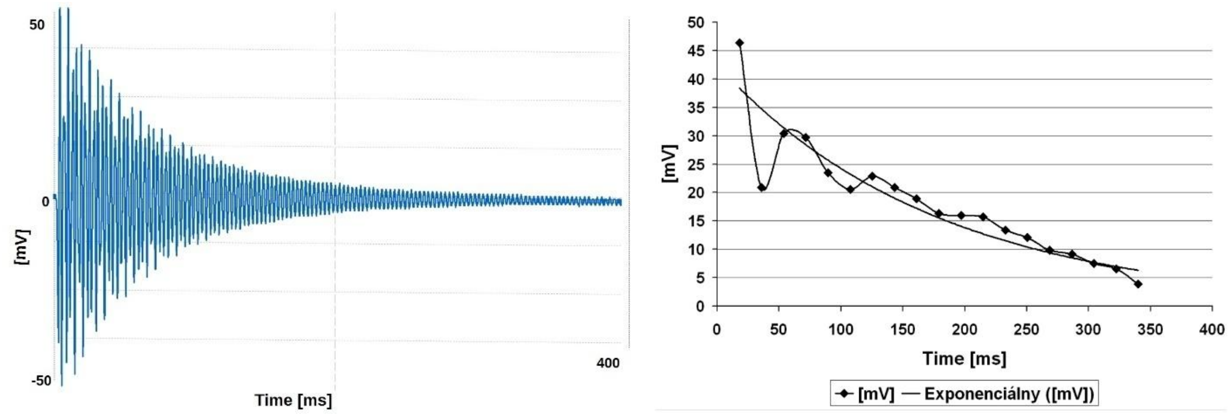
Mathematical Modelling

As the vibrations on the rod are excited, they are gradually damped as they oscillate. The vibrations are also dampened by the impact of pieces of paper. Damped vibrations of resonance frequency sensor are shown in Figure 4 (a), with its graphical representation and mathematical expression of trend line (b), which is of the exponential shape. The trend line was constructed through the least square as statistical method using the program system EXCEL as following:

$$y = 42.473e^{-0.0056\,t} \tag{3}$$

The value for the index of determination R^2 shows a suitable value of accuracy.

$$R^2 = 0.893$$



(a) (b)

Figure 4: Damped vibrations of resonance frequency sensor (a), with its mathematical representation and trend line (b), which is in the exponential shape

The damped vibrations are specified with the differential formula:

$$\frac{d^2y}{dt^2} + 2\zeta\frac{dy}{dt} + \omega_0^2 y = 0 \quad (4)$$

where

ω_0 ... the natural frequency of the system,

ζ ... the damping ratio of the system.

General solution (5) of the differential equation (4) is given as following:

$$y = e^{-\zeta t}(A_1 e^{\omega t} + A_2 e^{\omega t}) \quad (5)$$

Thus, through the comparison of the equations (4) and (5) we receive the value:

$$\zeta = 0.0056$$

So, the value of the damping ratio of the system equals 0.0056.

Distant Control System Using the Internet Connection

To keep the permanent control of the system with the resonance frequency sensor, monitoring via internet connection is managed as it is expressed in Figure 5.

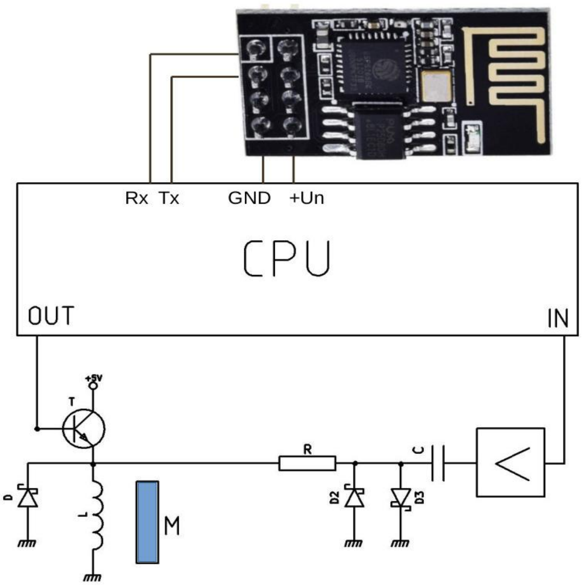


Figure 5: Schematic representation of the distant control of resonance frequency sensor with its circuit principle as well as the internet connection expressed

Diode D is a protection of transistor T against voltage peak, which occurs when the excitation of coil L is opened. Resistor R and anti-parallel Schottky diodes D2 and D3 limit the voltage course at the input of the amplifier, which is unidirectionally separated by capacitor C at the input of the amplifier itself. The output of the amplifier is connected to the "IN" input of the microprocessor. Transistor T is driven at the output of the processor "OUT". Rx and Tx are the input and output for communication with the network, respectively. GND and + Un (as indicated in the diagram on Figure 5) is the power supply of the external module ESP-01 S. During mechanical excitation, the magnet M is located at the end of the stainless steel non-magnetic rod.

Conclusion

To keep the requirements of the companies on the optimal process of the reverse logistics system with minimum costs as well as the suitable recycling technology or transportation to external company for further processing the optimum system with sometimes new equipment should be developed.

The waste material in the company for production of boxes is mostly paper. The waste paper is shredded and subsequently pelleted before the transportation to external company for the recycling. The paper is shredded directly in the hall with the production of boxes. The pieces of paper are transported through the pipes into the pelleting machine. The working chamber of pelleting machine requires monitoring against clogging.

The resonance frequency sensor prevents the clogging of the pipes as well as the working chamber that is used for pelleting with its possibility to monitor the paper movement in the chamber and by timely reporting the possibility of clogging via the internet connection.

In our future research in the field we focus especially on the modelling for optimization the costs included in the chain of the reverse logistics processes.

Acknowledgments

The research was conducted as a part of the international scientific project 05-6-1118-2014/2023 supported especially with the University of Prešov in Prešov, entitled: "Information and Computing Infrastructure of JINR".

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