DOI 10.52209/1609-1825_2021_3_48 UDC 681.586.711

Overview of Methods for Measuring Polymer Film Thickness to Create an Automated Real-Time Control System

[1]***NIKONOVA Tatyana,** *Cand. Tech. Sci., Associate Professor, nitka82@list.ru,*
[1]***DAICH Leonid,** *Senior Lecturer, l.daych@mail.ru,*
[1]***DANDYBAEV Esim,** *PhD, Senior Lecturer, y.dandybayev@hansa-flex.com,*
[1]***SICHKARENKO Andrey,** *Senior Lecturer, sichkarenko@gmail.com,*
[1]***BAIMULDIN Murat,** *doctoral student, murat_owl@mail.ru,*
[1]Karaganda Technical University, Kazakhstan, 100027, Karaganda, N. Nazarbayev Avenue, 56,
**corresponding author.*

Abstract. *The article deals with the problem of the integrity of the material of agricultural hoses made of three-layer polyethylene and the possibility of controlling the layers of the film. For the analysis, the manufacturers of industrial thickness gauges and the disadvantages of these measuring instruments are given. The input parameters for the choice of the method of measuring the film thickness are presented. The advantages and disadvantages of various methods for measuring the thickness of a polyethylene film in relation to the real conditions of the manufacturer are revealed. It is proposed to create an automated complex that makes it possible to control the thickness of the polyethylene film along the entire length of the shaft, excluding deformation and cuts of the film during extrusion. The principle of operation of the complex is described, which is based on the eddy current method of measurement with sensors and a registration unit using the contact principle of operation. The advantage of the developed control system is the transfer of data directly to the operator's computer in real time.*

Keywords: *sleeve, polymer film, thickness, control, automated system, method, sensor, extruder.*

Introduction

The main task of grain producers is to reduce costs and losses to a minimum, as well as profitable sales. The prices for the services of transport companies, the prices of elevators for drying, cleaning and storing grain significantly increase the cost of the final product (up to 50% of the cost of grain), which makes it less profitable to sell it [1, 2]. Farms are forced to store grain in currents and open areas unsuitable for long-term storage, which leads to a loss of its quality, and, as a consequence, to losses. The birthplace of grain storage technology is Argentina. This technology is also actively used in Canada, Australia, some other countries of the American continent, South Africa, France, Spain, etc. In the CIS countries, this technology has been used for several years, since it does not require large investments and can reduce storage costs by at least three times [3, 4]. The main principle of the technology is to store grain in an airtight environment, by pressing the mass in a special polyethylene sleeve, which is tightly closed after filling from both ends. This stops the oxygen supply. In the respiratory process, components that, along with the grain, get into the sleeve – insects and fungi, for example, – there is a decrease in the percentage of oxygen in the environment, and an increase in carbon dioxide. A new, optimal environment for storing grain automatically arises, in which the ability to live and develop is inactivated in insects and fungi.

This can only be ensured by ensuring the overall integrity of the materials from which the sleeves are made, consisting of three-layer high density polyethylene: the white outer layer contains titanium dioxide to reflect the sun's rays and prevents the temperature inside the sleeve from rising. One of the main qualities of polyethylene film for the production of agricultural hoses is its durability. It is achieved through the use of several different layers, as well as ensuring the specified parameters of the layer thickness. The control of the thickness of the film layers, as well as rejects in the case of ingress of various foreign bodies during extrusion, is carried out visually (which is very unreliable) or using thickness gauges of various designs and physical principles on which the thickness gauge is based. Industrial automated thickness measurement systems are not produced in Kazakhstan. Industrial thickness gages differ in their principle of operation, purpose, method and measurement accuracy.

The main manufacturers of industrial thickness gauges are: LLC "Fizpribor", LLC "SPC "KROPUS-PO", LLC "Acoustic Control Systems", LLC "KONSTANTA" (Russia), General Electric Company, StressTel Corporation (USA), Agfa-Gevaert Group (Belgium), Krautkramer Branson (Garmania), Olympus Corporation (Japan), Yunombo, Allsun, ETARI (China). Significant disadvantages of existing models of industrial thickness gauges are high manufacturing costs or high measurement errors.

Thus, the need to solve the production problem of designing and manufacturing an automated system for controlling the thickness of the film in the process of its manufacture is urgent.

Research methods

The input data for choosing a measurement method are the following parameters presented in Table 1.

To solve the problem, it is necessary to analyze and identify the advantages and disadvantages of various measurement methods, in relation to the real conditions of the polyethylene film manufacturer.

Results and Discussions

1. Capacitive measurement method

The capacitive measurement method is based on the difference in the dielectric constant of substances – air and polymer. The strip of film between the plates determines the capacitance of the capacitor. 2 types are used:

1) pin. Converts mechanical movement into capacitance change. For example, a signal converter for dial indicators;

2) contactless. The material to be examined is located between 2 plates.

The capacitive sensor is a flat capacitor, between the fixed plates of which a dielectric tape is drawn with the help of rollers [5]. The equivalent circuit of the converter consists of two (three) capacitors connected in series.

It should be noted that high measurement accuracy when using the contact method is possible only with ideal sliding of the sensor over the surface, which in our conditions is very difficult to implement, since the width of the web is 6 meters. The existing non-contact capacitive thickness gages are distinguished by high measurement accuracy, their error is measured in fractions of a micron, but in turn they have a rather high cost.

Other disadvantages of the capacitive principle of thickness measurement are the need for long-term calibration of sensors and periodic recalibration during operation, the appearance of errors due to changes in the gap, humidity or other random factors, the dependence of the readings when measuring the thickness of some polymers on temperature.

2. Optical measurement method

The optical method is implemented in scanning laser thickness gauges – these are non-contact film thickness control systems. They are most often incorporated into the extrusion line as they measure the thickness of the film web edge.

Their main advantages are the ability to control the thickness of the production process in real time and set the range of acceptable values. In case of any deviations, the system notifies the operator. Two parallel-positioned sensors ensure complete scanning of the film during production with a maximum error of 1 μm. A significant disadvantage of such systems is their high cost [6, 7].

Laser sensors require clear contours of the light spot. This is possible only for opaque surfaces, or transparent, but having a mirror surface [8]. In our case, the sleeve film is somewhere in between. Its surface cannot be called mirror-like, and its thickness can be called translucent. Worst of all, the beam of light is highly scattered both on the surface and in thickness. The stain is blurry. For stationary objects, this is still fixable, you can correct the result. But taking into account the fast motion of the film, the

Table 1 – Parameters for choosing a measurement method

Parameter name	Value
Control type	Non-destructive – continuous in real time
Working temperature range, °C	-20+30
Time of continuous work, h	8
Display of current thickness	+
Accumulation of information, T, period	1 month
Removable media transfer capability	+
Measured thickness range, mm	0,005-5
Accuracy, μm	±15
Alarm	+
Controlled web width, no more, m	6
Control over the entire width (allowed at several "migrating" points covering the entire width of the product per cycle)	+

boundaries of the spot become mobile, and the error reaches a value commensurate with the thickness of the film itself.

A worthy cost-effective replacement for expensive laser systems can be a film thickness measurement sensor based on the principle of infrared absorption. Among the visible advantages are a small measurement spot (2-5 mm), high measurement speed, advanced visualization tools.

These sensors measure both transparent and colored polymer films. High-precision measurement of the thickness of the product allows you to establish an optimal technological regime. Measuring the thickness directly during the film production process allows you to enter the production mode of quality products with minimal losses and waste during the launch and debugging of the technology. At the same time, the documentation of the technological process takes place, which helps prevent defective products from reaching the customer. Based on the analysis of an array of data on the thickness of the resulting film, it is possible to make informed decisions about reducing the thickness margin. Systems based on infrared sensors are supplied, for example, by the North American company NDC and cost about $ 50,000, which is their immediate disadvantage.

3. Eddy current measuring method

As a rule, devices operating according to this measurement method are produced in the form of combined models (eddy current thickness gages and magnetic thickness gages). The operation of such devices is based on magnetic induction (F-models) or eddy-current (N-models) principles of operation. The FN models use both operating principles.

The eddy current method is based on registering changes in the interaction of the coil's own electromagnetic field with the electromagnetic field of eddy currents induced by this coil in the controlled object [9].

A coil located in the thickness gauge probe, through which a high-frequency current flows, generates an alternating magnetic field. Approaching the surface under study, it excites Foucault currents in it – eddy currents that are captured and measured by the same or a secondary coil. Based on the measurement results, a conclusion is made about the thickness of the product.

Thickness gages based on this method are characterized by versatility, high accuracy and an advantageous price / performance ratio.

4. Radio wave measurement method

This method consists in irradiating the object under study with radio frequency radiation and measuring the parameters of the transmitted, reflected or scattered electromagnetic wave [10].

Radio wave methods are based on the registration and analysis of changes in the parameters possessed by the electromagnetic waves of the radio range (wavelength from 0.01 to 1 m) interacting with the control object. These methods can be used to control objects made of materials that do not "drown out" radio waves – dielectrics (ceramics), semiconductors, magnetodielectrics and thin-walled metal objects [11].

Radio wave methods can be considered as a kind of eddy current methods.

In both cases, the monitoring equipment consists of a microwave generator, a transmitting antenna, a receiving antenna, and a microwave measuring device.

5 Isotope measurement method

The isotope method is based on the registration and subsequent analysis of penetrating ionizing radiation interacting with the object. Depending on the type of ionizing radiation, the terms "X-ray", "neutron" and others may be used in the name of the methods [12].

Most often, gamma and X-ray radiation is used for control, which allows obtaining the maximum resolution.

6 Ultrasonic measurement method

The principle of operation of the thickness gauge is based on the ultrasonic pulse echo measurement method, which uses the property of ultrasonic vibrations to be reflected from the interface between media with different acoustic resistances [13]. The transmitting plate of the transducer emits an ultrasonic pulse through the delay line (prism) in the direction of the outer surface of the product, the thickness of which is to be measured. The ultrasonic pulse propagates in the product to the inner surface, is reflected from it, propagates in the direction of the outer surface and, having passed the delay line (prism), is received by the receiving plate.

7 Mechanical measurement method

The method consists in measuring the thickness of the film using passimeters (lever bracket) and micrometers [14].

We will not even consider the variant of the passimeter, since this tool is designed for "rough" quick control "in tolerance – not in tolerance" of the real size of the part, usually in the serial production of parts. A standard micrometer is also not quite suitable for measuring polymer films, since when the measuring rod rotates during contact with the film surface, shear deformation occurs, in addition, the magnitude of the measuring force depends on the operator. The error of measurement carried out with a standard digital micrometer varies from 5 to 10 microns, depending on the qualifications of the specialist, the thickness and material of the film. Whereas the measurement error using an indicator thickness gauge and a micrometer with a constant force is 2-3 microns. This means that a company that uses a micrometer to control the film thickness makes a film with a greater thickness, that is, it has an extra waste of material.

Conclusions

From the analysis carried out, it is possible to draw up a comparative table (Table 2) of the existing measurement methods in relation to polyethylene

Table 2 – Comparative analysis of measurement methods

Method of measurement	Advantages	Disadvantages
	Contactless methods	
	General for this method: 1. Absence of mechanical contact between the control device and the surface of the film web	General for this method: 1. Increased requirements for the homogeneity of raw materials (its physical properties) 2. The need for strict adherence to the stability of atmospheric parameters (temperature, humidity)
1. Optical methods (Scanning laser, interferometer, reflectometry, infrared tempe-rature stabilized sensors)	1. Continuous real-time thickness control 2. High precision	1. Applicable for homogeneous material 2. High cost 3. Unevenness of the film surface affects the error 4. High dustiness in an industrial environment reduces measurement stability 5. Shaft runout and vibration increase the measurement error
2. Radio wave	1. Continuous real-time thickness control 2. High precision	1. The main limitation is harmful high frequency radiation
	Contact methods	
	General for this method: 1. Simplicity and high performance 2. Cost effective	General for this method: 1. Wear of the point of contact 2. Risk of damage to the film web
1. Ultrasonic method	1. A proven method. 2. Reasonable cost of serial samples.	1. The range of measured values (from 1mm) does not correspond to the specified one. 2. The need for the constant availability of contact grease. 3. Restrictions on the acoustic properties of the material.
2. Eddy current method	1. The measurement accuracy is independent of shaft runout, bearing wear, structural deformation, etc. 2. The most suitable for climatic conditions.	-
3. Semiconductor dial indicator (displacement sensor)	1. Availability of a standard interface for signal transmission. 2. Carbide point of contact with the measured film.	1. The measurement accuracy depends on shaft runout, bearing wear, structural deformation, etc. 2. Limited temperature range.
	Generic methods	
1. Capacitive method	1. Tested method	1. Dependence on material properties 2. Dependence on temperature and humidity, on static electricity 3. With the contact method, beating and vibration errors are added

films for the manufacture of agricultural hoses based on the specific production conditions.

Drawing conclusions, we can say the following, in the case of the existing production conditions and with the need to manufacture sleeves for storing grain, satisfying the quality and cost of the consumer, it is necessary to create an original model of the hardware and software complex that makes it possible to control the thickness of the polymer film layers along the entire length of the shaft, excluding deformation of the film as a result of the ingress of foreign bodies during extrusion (cuts).

The most appropriate design solution would be to use the eddy current measurement method in the system. The automated system will consist of several sensors operating according to this principle and a registration unit. The principle of operation is contact. The gap measurement will take place between the sensor and the metal surface of the roller formed by the material being measured. The sensor must be located in a movable carriage and spring-loaded to ensure guaranteed contact with the plastic film in case of possible vibrations.

To increase the life of the sensor, it is necessary to use a replaceable non-magnetic gasket with a minimum sliding friction coefficient and maximum wear resistance. The data transfer will be carried out to the operator's computer in real time and integrated into the equipment operating mode control system, which will allow the extruder nozzles to be calibrated.

This research has been/was/is funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP08052553).

REFERENCES

1. Диханова М.Б. Хранение зерна под пленкой / Диханова М.Б. // Материалы Республиканской научно-теоретической конференции «Сейфуллинские чтения – 11: Молодежь и наука», Астана, 2015. – С. 17-18.
2. Buryanov A.I., Dmitrenko I.A. Device for placement of grain for storage, comprises main receiving de-vice and packaging machine oriented parallel to each other and aggregate with truck tractors / Патент России, №: RU2529747-C1, 2014, Бюл. № 27.
3. ADAM J., ADAM A.J. Agricultural grainy prod-uct storing process, involves filling dry grainy products into plastic sleeves, and controlling concentration of gas i.e. carbon dioxide, in sleeves and setting optimal concentration if neces-sary. Patent Number: HU200500144-A1; HU227636-B1, 2014.
4. Мырзабекова А.М. Обзор современных систем для хранения зерновых культур // VI Научно-практическая конференция «Информационно-измерительная техника и технологии», 27-30 мая 2015 г. – С. 95-101.
5. Солобченко Г.Н. Электрические измерения неэлектрических величин / Новицкий П.В. – СПб: Изд-во ПУ, 2011. – 256 с.
6. Дивин А.Г. Методы и средства измерений, испытаний и контроля: учебное пособие. В 5 ч. – Тамбов: Изд-во ГОУ ВПО ТГТУ, 2011. – 104 с.
7. Прокопенко В.Т. Оптические измерения: Конспект лекций. – СПб: СПбГИТМО, 2012. – 322 с.
8. Селиванов М.Н. Качество измерений. Метрологическая справочная книга / Селиванов М.Н., Фридман А.Э. – Л.: Лениздат, 1987. – 370 с.
9. Хорошайло Ю.Е. Вихретоковый толщиномер неферромагнитных покрытий / Хорошайло Ю.Е. // Тез. докл. X Всесоюз. науч.-техн. конф. «Неразрушающие физ. методы и средства контроля». – 2014, С. 193-195.
10. Матвеев В.И. Радиоволновой контроль. – М.: Изд. Дом «Спектр», 2011. – 184 с.
11. Алешин А.А. Радиационная, ультразвуковая и магнитная дефектоскопия металлоизделий. – М.: Высш. шк., 2011. – 271 с.
12. Zavialkin F.M. Estimatingthe performance of a differential counting method of measuring material thickness // Soviet Journal of Nonde-structive Testing. – 1985 – Vol. 21 – No. 4 – P. 275-279.
13. Кретов Е.Ф. Ультразвуковая дефектоскопия в энергомашиностроении / Кретов Е.Ф. – СПб: Свен, 2011. – 305 с.
14. Смышляев А.Р. Коррекция толщины полимерных пленок в процессе их изготовления // Полимерные материалы. – 2007. – № 12. – С. 10-16.

Нақты уақытта автоматтандырылған басқару жүйесін құруға арналған полимерлі пленканың қалыңдығын өлшеу әдістеріне шолу

*[1]***НИКОНОВА Татьяна Юрьевна,** т.ғ.к., доцент, nitka82@list.ru,*
*[1]**ДАЙЧ Леонид Израильевич,** аға оқытушы, l.daych@mail.ru,*
*[1]**ДАНДЫБАЕВ Есім Серикович,** PhD, аға оқытушы, y.dandybayev@hansa-flex.com,*
*[1]**СИЧКАРЕНКО Андрей Владимирович,** аға оқытушы, sichkarenko@gmail.com,*
*[1]**БАЙМУЛЬДИН Мұрат Мұратұлы,** докторант, murat_owl@mail.ru,*
[1]Қарағанды техникалық университеті, Қазақстан, 100027, Қарағанды, Н. Назарбаев даңғылы, 56,
**автор-корреспондент.*

Аңдатпа. *Мақалада үш қабатты полиэтиленнен жасалған ауылшаруашылық шлангтарының материалының тұтастығы және пленка қабаттарын басқару мүмкіндігі қарастырылады. Талдау үшін өнеркәсіптік қалыңдық өлшегіштердің өндірушілері және осы өлшеу құралдарының кемшіліктері келтірілген. Кіріс параметрлері пленканың қалыңдығын өлшеу әдісін таңдау үшін ұсынылған. Өндірушінің нақты жағдайларына қатысты пластикалық пленканың қалыңдығын өлшеудің әртүрлі әдістерінің артықшылықтары мен кемшіліктері анықталды. Экструзия кезінде пленканың деформациясы мен кесілуін қоспағанда, біліктің бүкіл ұзындығы бойымен пластикалық пленканың қалыңдығын бақылауға мүмкіндік беретін автоматтандырылған кешен құру ұсынылады. Жұмыстың байланыс принципін қолдана отырып, датчиктермен және тіркеу блогымен құйынды ток өлшеу әдісіне негізделген кешеннің жұмыс принципі сипатталған. Дамыған басқару жүйесінің артықшылығы – деректерді нақты уақыт режимінде оператордың компьютеріне тікелей жіберу.*

Кілт сөздер: *жең, полимерлі пленка, қалыңдығы, бақылау, автоматтандырылған жүйе, әдіс, датчик, экструдер.*

Обзор методов измерения толщины полимерной пленки для создания автоматизированной системы управления в реальном времени

[1]****НИКОНОВА Татьяна Юрьевна,*** *к.т.н., доцент, nitka82@list.ru,*
[1]***ДАЙЧ Леонид Израилевич,*** *старший преподаватель, l.daych@mail.ru,*
[1]***ДАНДЫБАЕВ Есим Серикович,*** *PhD, старший преподаватель, y.dandybayev@hansa-flex.com,*
[1]***СИЧКАРЕНКО Андрей Владимирович,*** *старший преподаватель, sichkarenko@gmail.com,*
[1]***БАЙМУЛЬДИН Мурат Муратович,*** *докторант, murat_owl@mail.ru,*
[1]*Карагандинский технический университет, Казахстан, 100027, Караганда, пр. Н. Назарбаева, 56*

**автор-корреспондент.*

Аннотация. *В статье рассматриваются проблема целостности материала сельскохозяйственных шлангов из трехслойного полиэтилена и возможности управления слоями пленки. Для анализа приведены производители промышленных толщиномеров и недостатки этих измерительных приборов. Представлены входные параметры для выбора метода измерения толщины пленки. Выявлены преимущества и недостатки различных методов измерения толщины полиэтиленовой пленки по отношению к реальным условиям производителя. Предлагается создать автоматизированный комплекс, позволяющий контролировать толщину полиэтиленовой пленки по всей длине вала, исключая деформацию и разрезы пленки при экструзии. Описан принцип работы комплекса, в основе которого лежит вихретоковый метод измерения с датчиками и блоком регистрации с использованием контактного принципа работы. Преимуществом разработанной системы управления является передача данных непосредственно на компьютер оператора в режиме реального времени.*

Ключевые слова: *рукав, полимерная пленка, толщина, контроль, автоматизированная система, способ, датчик, экструдер.*

REFERENCES

1. Dikhanova M.B. Grain storage under a film / Dikhanova M.B. // materials of the Republican scientific-theoretical conference "Seyfullin reading – 11: Youth and science", Astana, 2015. – P. 17-18.
2. Buryanov A.I., Dmitrenko I.A. Device for placement of grain for storage, comprises main receiving device and packaging machine oriented parallel to each other and aggregate with tractors truck / Patent of Russia №: RU2529747-C1, 2014, bull. No. 27.
3. ADAM J., ADAM A.J. Agricultural grainy product storing process, involves filling dry grainy products into plastic sleeves, and controlling concentration of gas i.e. carbon dioxide, in sleeves and setting optimal concentration if necessary. Patent Number: HU200500144-A1; HU227636-B1, 2014.
4. Myrzabekova A.M. Review of modern systems for storing grain crops // VI Scientific and practical Conference "Information and measuring equipment and technologies", May 27-30, 2015. – P. 95-101.
5. Solobchenko G.N. Electrical measurements of non-electrical quantities / Novitsky P.V. – St. Petersburg: Publishing house of PU, 2011. – 256 p.
6. Divin A.G. Methods and means of measurement, testing and control: a textbook. At 5 o'clock. – Tambov: Publishing house of GOU VPO TSTU, 2011. – 104 p.
7. Prokopenko V.T. Optical measurements: Lecture notes. – St. Petersburg: SPbGITMO, 2012. – 322 p.
8. Selivanov M.N. The quality of measurements. Metrological reference book. / Selivanov M.N., Fridman A.E. – Leningrad: Lenizdat, 1987 – 370 p.
9. Khoroshaylo Yu.E. Eddy current thickness gauge of non-ferromagnetic coatings / Khoroshaylo Yu.E. // Tez. dokl. X All-Union. sci.-tech. conf. "Non-destructive physics. methods and means of control". – 2014, P. 193-195.
10. Matveev V.I. Radio wave control. – Moscow: Ed. House "Spectrum", 2011 – 184 p.
11. Aleshin A.A. Radiation, ultrasonic and magnetic flaw detection of metal products. – Moscow: Higher school, 2011. – 271 p.
12. Zavialkin F.M. Estimatingthe performance of a differential counting method of measuring material thickness // Soviet Journal of Nonde-structive Testing. – 1985 – Vol. 21 – No. 4 – P. 275-279.
13. Kretov E.F. Ultrasonic flaw detection in power engineering / Kretov E.F. – St. Petersburg: Sven, 2011 – 305 p.
14. Smyshlyaev A.R. Correction of the thickness of polymer films in the process of their manufacture // Polymer materials. – 2007. – No. 12. – P. 10-16.