THE FACILITY FOR RADIATION PROCESSING OF THERMOSHRINKABLE WIRING PRODUCTS WITH LINAC UELR-10-10T

M.I. Demsky, V.V. Krotov, D.E. Trifonov, «NPP «CORAD» Ltd
M.F. Vorogushin, FSUE “NIIEFA”, Saint Petersburg, Russia
V.G. Ostapets, N.M. Chelnakov, Physical and Chemical Karpov Institute, Obninsk, Russia
A.G. Gerasimenko, A.N. Razuvaev, JSC «Podolsk plant for wiring products», Podolsk, Russia

Abstract

A technological unit for irradiation modification of polymer pipes used to manufacture thermo-shrinkable cable couplings was put into operation at the branch of Physical and Chemical Karpov Institute in Obninsk at the end of 2005. The unit was created based on the modern electron linac UELR-10-10T with electron energy 10 MeV at beam power 10 kW. The linac contains original solid-state modulators for the klystron and electron gun, due to which the efficiency of power transfer from the network to the beam in the unit reaches the value 16%. Due to the vertical beam scanning system irradiation field can be changed within the range 90-170 cm at dose heterogeneity along the pipe length of no more than ±5%. Irradiated polyethylene (PE) pipes with wall thickness up to 6 mm and up to 150 cm long are installed vertically in three rows along the perimeter of the rotating drum 3.7 m in diameter. In the process of irradiation the pipes are rotating around their axes; in this way high homogeneity of the irradiation dose is achieved and as a result high quality products are produced.

INTRODUCTION

Polymer thermo-shrinkable items based on PE have been more and more used lately to manufacture coupling and terminal boxes for high-voltage cable networks. The application of PE as a material to make thermo-shrinkable items is connected with the ability of methylene chains within the polymer macro-molecules to produce ionizing radiation-effected cross-links when thermoelastic 3-D net is initiated. At the same time, the linked amorphous-crystalline polymer gains so-called «memory effect» - the ability to be back to its initial size and shape after the cycle of heating, mechanical strain (tension), loaded cooling and second cooling.

The cost of radiation processing using the electron accelerator depends on the ratio of the output electron beam power to the total consumed power, which is determined by the structure of the electron accelerator itself and the radiation efficiency determined by the radiation technology.

THE MAJOR PARAMETERS AND DESIGN OF THE ACCELERATOR

The accelerator UELR-10-10T has the following major parameters:

- Electron energy range: 8.5-11 MeV;
- Average beam power for 10 MeV: 10 kW;
- Pulse repetition rate: 50, 100, 200 1/sec;
- Beam current for 10 MeV: 310 mA;
- Output window length: 800 mm;
- Irradiation field length with dose variations ±5%: 1700 mm;
- Power consumption: 62 kW.

The accelerator contains the following principal units:

- Irradiator (the unit for electron beam acceleration) 3 m in length
- Klystron unit with a pulse transformer ($600\times600\times1550$ mm^3)
- Solid-state pulse modulator for the klystron ($600\times1200\times2100$ mm^3)
- Control system
- Power supply rack
- Klystron cooling system
- Irradiator cooling system

Figure 1: Irradiator with klystron unit.

The irradiator, the klystron and transformers of the klystron and the electron gun are placed inside shielding. The other pieces of equipment are located outside the irradiation zone. The klystron and electron gun modulators are connected to output high-voltage transformers by means of high-voltage cables for pulse voltages 11 kV and 6 kV respectively. The accelerator has a standing wave accelerating structure with the length 1.1 m and working frequency 2856 MHz. The source of high frequency power is Russian multi-beam klystron KIU-147 A with pulse power 6 MW and average power 25 kW. The klystron is operated at cathode voltage 51 kV and pulse current 260 A. Focusing field inside the klystron is provided by permanent magnets.

The diode electron gun with a dispenser BN-cathode 14 mm in diameter is operated at nominal voltage 50 kV. A focusing coil and a diaphragm are installed at the electron gun output. When current inside the focusing coil is changed the electron beam diameter on the diaphragm changes and due to this fact the electron beam current is regulated at the accelerating structure input. The focusing coil current is regulated by computer control system so that the amplitude of output beam current measured by a magnet-induced sensor under the transformer current mode is kept constant.

Control System For Electron Beam Parameters

An air ionization chamber is installed behind the accelerator output window to control the scanning length and energy of electrons in the process of irradiation; it contains two continuous collecting electrodes having the potential +100 V and a number of measuring electrodes in the form of foil stripes, placed over the whole scanning length among the continuous electrodes perpendicular to the sweep trace. The electrodes are made of titanium foil 10 microns thick. The computer specifies the shape of current in the scanning magnet. When current in the scanning magnet achieves the maximum and minimum values, its amplitude and output signals from the individual foil stripes in the ionization chamber are registered simultaneously. This information is used to measure the scanning length. Based on the known current value in the magnet and signals distribution among the measuring electrodes with the accuracy of about 6% one can determine the energy of electrons.

The Klystron Modulator

The modulator of klystron employs a well-known scheme with an inductive voltage adder like in linear induction accelerators. The total output voltage is a result of adding voltage of 40 cores, each being a load of a pulse forming line (PFL) commutated by thyristors. Low level of voltage in the scheme of the thyristor pulse modulators made it possible to develop effective recuperation circuits, as a result of which the efficiency of the modulator achieved 86%.

The output voltage of 11 kV is applied to the input of the high-voltage pulse transformer through four cables 10 m long. The output voltage is regulated by switching off the IGBT transistor in the charging unit when the required voltage level in the cores is achieved.

The accelerator UELR-10-10T was created by NIIEFA in cooperation with «NPP «CORAD» Ltd. (Saint Petersburg). The irradiator and cooling systems were made in NIIEFA. The enterprise «NPP «CORAD» Ltd. developed and manufactured the accelerator control and power supply systems as well as they performed installation and setup of the accelerator equipment.

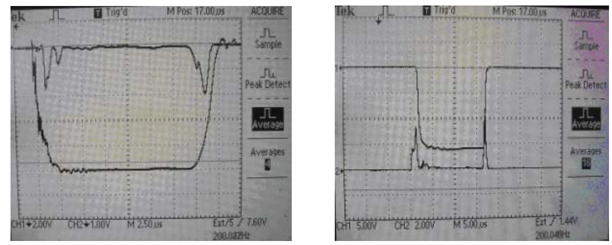

Figure 2: Pulses of klystron current and beam current on the background of reflected high-frequency wave signal.

THE RESULTS OF EXPERIMENTAL RESEARCH ON THE UNIT APPLICATION TO PRODUCE THERMO-SHRINK ITEMS

During the production of thermo-shrinkable items for cable industry from polymer materials based on polyolefines the items are irradiated up to the value of absorbed dose of 100-120 kGy; as a result, a gel-fraction is generated and it determines the degree of cross-linking in the polymer in the range of 55-65%. The polymers with the degree of cross-linking like this have optimal properties to be used in the manufacturing of thermo-shrinkable insulating items (terminators, pipes, gloves, insulators).

In the process of execution of the operating practices for cross-linking of polymer items produced by JSC «Podolsk plant for wiring products» in the accelerator UELR-10-10T at the branch of Physical and Chemical Karpov Institute, experimental results were obtained; they characterize both radiation modification modes and the properties of the obtained thermo-shrinkable products.

Polymer pipes manufactured by means of extrusion method from cable PE, grade 153-10 K were irradiated. The PE pipes had an internal diameter from 20 up to 40 mm and wall thickness from 4 up to 6 mm. The length of the irradiated pipes was changed from 100 up to 150 cm.

Irradiation was performed at the abovementioned accelerator parameters and energy of electrons 9.6 MeV. The value of vertical beam scanning on the output foil was equal to 50 cm for the pipes up to 120 cm long and 60 cm for the pipes over 120 cm long. The pipes placed in three rows in the rotating carrousel were additionally rotating around their axes during irradiation. 450 pipes were simultaneously irradiated in the carrousel.

To practice the irradiation modes in order to optimize the properties of thermo-shrinkable products the following investigations were conducted:

Firstly, dependence of the degree of cross-linking of a polymer pipe on the absorbed dose value was determined.

Secondly, ultimate elongation value for a polymer pipe at temperature 130^{O}C, which determines the ability of the pipe to change its size in the process of radial orientation under thermal bulging, was investigated.

Strength properties of the polymer pipe, i.e. dependence on the load required for radial orientation at temperature 130^{O}C were investigated as well. This value finally determines the load created in the inner part of the thermo-shrinkable pipe during the installation (thermo-shrinkage). Insulation quality greatly depends on compaction load of melted glue of the sealing material in the process of thermo-shrinkage.

Figure 3: Irradiation zone for products.

Figure 4 represents the investigation results on the degree of cross-linking based on the value of the gel-fraction content in the irradiated material.

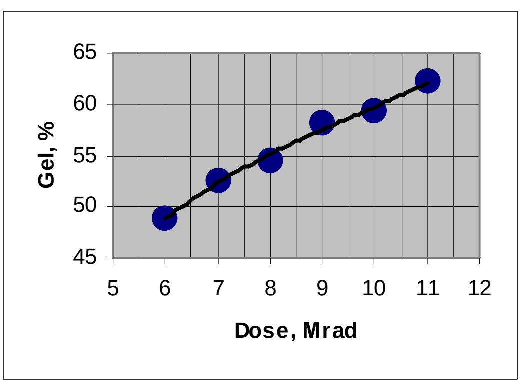

Figure 4: Cross-linking of thermo-shrinkable pipes from PE-153-10K vs. the absorbed dose.

As a rule, in practice thermo-shrinkable products from PE 153-10K are manufactured in the range of values for gel-fraction from 55 up to 62%. From figure 4 it is evident that the values are reached at the absorbed doses from 8 up to 10.5 Mrad (80-105 kGy).

Figure 5 shows measurement results of ultimate elongation for the polymer pipe specimens irradiated to different absorbed doses. The measurements were carried out at temperature 130^{O}C.

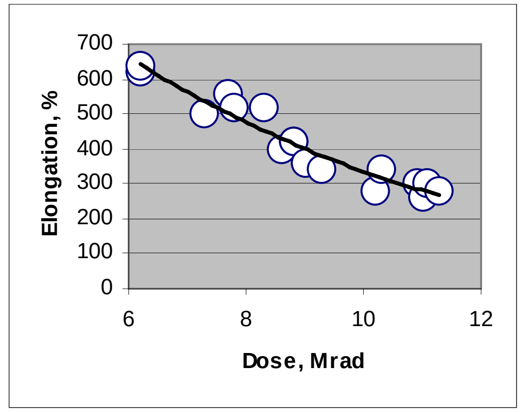

Figure 5: Ultimate elongation of polymer pipe specimens depending on the dose.

From figure 5 one can see that at the abovementioned valued for gel fraction a polymer pipe after irradiation keeps the ability to change its diameter from 4.5 up to 3.2 times. A billet with the inner diameter 30 mm can be bulged up to the diameter of more than 90 mm.

Figure 6 represents the investigation results showing change of compacting load value at shrinkage depending on the absorbed dose value. The figure shows elongation load values specified for the cross section of the initial specimens. The elongation loads were measured at crystallite melting temperatures (130^{O}C). At these temperatures a non-cross-linked polymer melts and turns into a viscous liquid.

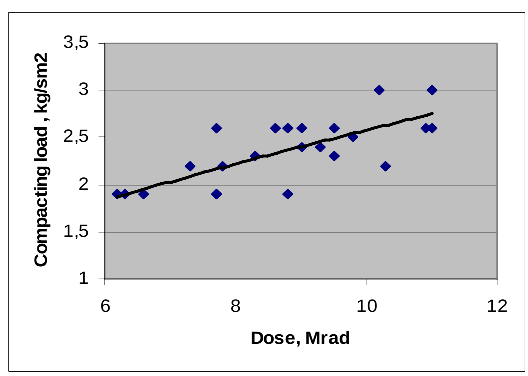

Figure 6: Compacting load value at shrinkage vs. the absorbed dose value.

Within the dose range, where gel-fraction content is equal to 55-62%, in the process of shrinkage of a thermo-shrinkable pipe, compression stress affecting the pipe will be at least 2.2-2.8 kg/cm^2.

To obtain optimal properties of the thermo-shrinkable pipe with bulge ratio 3-3.5 a polymer billet pipe has to be irradiated up to the absorbed dose value 9.5-10.5 Mrad. At the same time, a thermo-shrinkable pipe under shrinkage will be shrunk with compacting stress 2.5-2.8 kg/cm^2. Gel-fraction content in the cross-linked polymer is 57-62%.