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Use of polymers at electroinsulating parts production

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Abstract: *Main objective of work is generalization of researches results in a polymers scope as electroinsulating material. Key parameters of electroinsulating parts are considered. Characteristics and recommendations about use of polymers are provided in instrument making products. As a result, the choice algorithm of polymer at production of electroinsulating parts which allows finding rational material is offered. Properties of the chosen polymer need to be considered at design of the forming tool for receiving a qualitative polymeric part.*

Keywords *- Application, Polymer, Choice, Properties, Electroinsulating Part.*

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I. Introduction

Along with metals and alloys, polymers (PM) are also widely used in industry. Products made of polymers are usually manufactured by compression or injection molding and, in the future, require almost no machining. In this case, polymer products have a number of valuable electrical, mechanical and physical-technical properties [1].

One of the directions of the polymers use are electrical insulating parts (EIP). This production is used practically in all branches of industry: power, chemical, electrotechnical, metallurgical, instrument making, machine building, construction [2].

Some materials used in electrical appliances and power supply schemes have dielectric properties, that is, they have a high current resistance. This ability allows them not to pass current, and therefore they are used to create insulation of live parts. Electrical insulation materials are not only designed to separate current-carrying parts, but also to create protection against the dangerous effects of electric current. For example, the power cords of electrical appliances are covered with insulation [3].

The normal operation of an electrical appliance or the safety of a power supply scheme largely depends on the dielectrics used. Some parameters of the material intended for electrical insulation determine its quality and capabilities.

Thus, consideration of the using polymers possibility and the adequacy of their use in industry is one of the scientific research areas that can improve the reliability and products quality that are manufactured.

II. Materials and Methods

2.1 Review of the literature on the research topic

In [1] the entity of polymers as constructional materials is opened, their classification, a structure and properties from the view point of constructional material are considered. Polymers classify by the nature of receiving binding substance as condensation and polymerization. In [1] it is defined that the most widespread material in instrument making heat-convertible condensation polymers – phenoplast and aminoplastics. Carry thermoplastic materials to number of the most important polymers – polyethylene, polyvinyl acetate, polystyrene, polytetrafluorethylene, etc.

In [2] bases of operation and electric equipment diagnostics, the organization of maintenance and electrical machines repair are given. Electroinsulating materials for production of traction electric motors isolation systems and also direct current motors of classes B, F and H are considered. Electroinsulating materials for low-voltage electrical machines.

Measurement methods of dielectric characteristics electroinsulating materials are presented in [3], having high precision. The method of the volume cylindrical resonator and a method of the waveguide and dielectric resonator developed are among such methods. In the considered measurement methods the «contribution» to dielectric losses gives «all volume» of a sample therefore oxidation of a thin polyethylene influences blanket of the dielectric losses tangent angle value measured a little. Assessment of various methods accuracy allowing to measure dielectric characteristics of polymeric materials, and possibilities of their application for entrance control of electroinsulating materials was at the same time carried out. In [3] it is defined that dielectric losses of polymeric dielectrics depend on moistening extent, impurity availability and air bubbles in polymer. Electroinsulating material is better for those, than the value of an angle losses tangent is less, that is, dielectric losses are lower.

In [4] it is about electroinsulating materials which are applied in multilayered printed circuit boards. The refusals of isolation is analyzed, it is defined that their main sources are local defects of dielectric: the sites which aren't filled with pitch; local stratifications or weak coupling of layers multilayered printed circuit boards; foreign particulates and pollution between layers. It is defined that such defects lead to formation of longitudinal microcavities along layers of payments.

Constructional products for electronic and radio engineering products are presented in [5]. Scopes of polymers as electroinsulating materials are considered. Characteristics of polymers and their feature are provided. Examples of the structural polymers used in the frictional knots subjected to mechanic -chemicals wear and polymeric films / coverings for protection of metal objects against corrosion are given. In [5] the thermodynamic principles of the electroinsulating materials choice, their compatibility and their efficiency are described.

At design of a product his material and components have correspond to completely set conditions. At the choice of electroinsulating parts material it is necessary to consider their appointment. And determination of materials properties is significant to perform the functions.

At a solution of the choice of polymers for EIP problem it is important analysis of the main various polymers properties, their advantages and restrictions on application and also PM classification by operational appointment with recommendations about their rational application. Also at the choice of PM consider recommendations by processing methods, preparation conditions for processing and by formation.

Thus, the choice of PM for EIP – one of the major stages at design of parts, so, a research problem of polymers properties, applied to production of electroinsulating parts is relevant.

2.2 Basics of polymer research in the EIP manufacture

To produce EIP at the present time, various, often very complicated methods of chemical synthesis, lamination, extrusion, pressing, various types of processing are used [6, 7].

The bases for the production of electrical insulating materials are synthetic resins, plastics, polymers, fiberglass, natural and synthetic fabrics.

In the manufacture of electrical insulating parts, the main parameters include electrical strength, specific electrical resistance, relative permittivity, and dielectric loss angle. Electrical strength – the strength of the field at which the breakdown occurs (the material loses its electrical insulating properties is the so-called dielectric breakdown) [8, 9]. Specific electrical resistance is a physical quantity characterizing the ability of a substance to prevent the passage of an electric current [10]. Relative permittivity is the ratio of the capacitor capacity with a given dielectric to the capacitance of a capacitor of the same geometric dimensions, but the insulator of which is air (vacuum). The ability of a dielectric to dissipate energy in an electric field is usually characterized by the dielectric loss angle, as well as the tangent of the dielectric loss angle. During the test, the dielectric is considered as the dielectric of the capacitor, in which the capacitance and angle δ are measured, supplementing up to 90° the angle of phase displacement between the current and voltage in the capacitive circuit. This angle is called the dielectric loss angle [11].

When evaluating the electrical insulation properties of the material, the dependence of the listed characteristics on the electric current values and voltage is also taken into account. EIP and materials have a greater value of electrical strength in comparison with conductors and semiconductors. Also important for the dielectric is the stability of the specific values when heated, increasing the voltage and other changes.

The characteristics and recommendations for the polymers use for instrumentation products are given in Table-1 [12].

For the manufacture of EIP there are special materials – electrical insulating materials (EIM). Classification of EIM (dielectrics) is based on their aggregate state (solid, liquid and gaseous) and origin (organic: natural and synthetic, inorganic: natural and artificial). The most common type of solid EIM, which can be seen on the cord of household appliances or any other electrical appliances [10].

Solid dielectrics are divided into nonpolar, polar and ferroelectrics. Their main differences are in the mechanisms of polarization. This insulation class has such properties as chemical resistance, tracking, dendrites. Chemical resistance is expressed in the ability to withstand the influence of various aggressive environments (acid, alkali, etc.). The resistance to corrosion is determined by the ability to withstand the effects of an electric arc, and dendrites resistance to the formation of dendrites [12].

Table 1 Characteristic and recommendations about use of polymers for instrument making products

Name Material, his brand	The recommended application	Processing characteristics					
		Specific pressure optimum	Hold time on 1 mm of thickness	Temperature pressing		Preheating	
				Without heating	With heating	Temperature	Time
		Kg/sм^3	min.	°C			min.
Glass-textolite, STK-41	Blocks, rollers, plugs insulating	-	-	-	-	-	-
Fluoroplast – 3	For electroinsulating devices parts of the low-frequency equipment production and also for production of suspensions for electroinsulating and corrosion-resistant coatings	300 – 500	Coolings to 100 – 120°C	220	-	-	-
Fluoroplast – 4	For production of insulators through passage, plugs, panels, etc. Films for interlayered isolation in the high-frequency equipment	Not less 200	Pressing on cold and agglomeration at a temperature of 360 - 370 ° C				
Polyethylene, PE-300, PE-450	Planimetric coils, condensers, frameworks, level	200	Cooling up to 40 – 50 ° C	160 – 180	-	175 – 250	-
Polystyrene Block, D	Parts of the high-frequency equipment: frameworks of coils, panels, insulators. Laying, caps, levels for high-frequency condensers	200 – 400	1 – 1.5	135 – 170	-	-	-
Polystyrene emulsion, A	Frameworks, tips, panels, laying, caps	150 – 200	1 – 1.5	135 – 160	-	-	-
Polyamide resin	Plug connectors, lamp panels, casing of variable resistances	150 – 180	-	250 – 260	-	-	-

III. Results

The design of EIP in general includes the following stages:
- choice of the part shape;
- material selection;
- calculations (the projected EIP should be reliable in operation, it should provide performance characteristics in accordance with the requirements, the designed EIP should be given an economic evaluation);
- creation of working design documentation.

The process of designing EIP from polymers should ensure the maximum process design. This involves achieving a minimum cost, saving material, simplifying the design of the forming tool, increasing the reliability and durability of the part.

The following algorithm for choosing a PM for the manufacture of EIPs is proposed:

1 Stage – definition: EIP work at high humidity? If – "no", that is, EIP works at normal humidity, then go to step

2. If the condition is fulfilled "yes", the PM must have properties that are not dependent on humidity. Stage – definition: EIP works at the increased temperature? If the condition is satisfied "yes", then PM has to have the properties which are a little depending on temperature. If – "no", then we pass to a stage 3. When conditions 1 and 2 stages are satisfied, it will be necessary to choose PM with high heat resistance and small water absorption capacity and pass to a stage 4.

3 Stage – definition: EIP works at the lowered temperature? If the condition is satisfied "yes", then PM has to have property of frost resistance without manifestations of fragility, so, it is necessary to determine parameter T_{fb} (fragility at a bend) (stage 3.1) [12, 13]. If – "no", then we pass to a stage 6 (definition loading type).

4 Stage – definition: EIP works at short-term increase (up to 3 min.) temperature? Then it is necessary to choose PM with high heat resistance and if at the same time external mechanical loading (stage 5) doesn't act on EIP. Thus, PM has to have resistance to softening, further it is necessary to determine parameter – softening temperature on Vick $T_v, {}^oC$ at loading 9,8 N (stage 5.1) [12]. Further we pass to a stage 6.

5 Stage – definition: whether EIP are subject to "considerable" loadings.

If there is a long operation at the increased temperature (mechanical loading is possible), so PM has to have resistance to softening. Then it is necessary to determine parameter – softening temperature at a bend $T_{sb}, {}^oC$ (softenings at a bend) (stage 5.2) [12] and then we pass to a stage 6.

In a case, at long operation (operation time $v_{ot} > 3$ min) of EIP at the increased temperature, but without mechanical loading, further it is necessary to determine parameter – temperature of long operation $T_{lo}, {}^0C$ (stage 5.3) which will pay off for the period in 10 years: $T_{lo} = \Sigma T_{lo1} + T_{lo2} + ...T_{lo10}$ [12]. Further we pass to a stage 6.

If EIP works at a normal temperature, then transition to definition loading type (stage 6). After the choice of such material properties (high heat resistance, small water absorption capacity, frost resistance without manifestations of fragility, etc.) also we pass to definition loading type.

6 Stage – definition loading type. If EIP works at the enclosed loading during 1 – 3 sec., then we define loading type: stretchings, bend, compression.

6.1 Stage – definition: loading type "stretching" acts on EIP? If "yes", then we define resistance to fluidity, namely, a fluidity limit at stretching σ_{fs} (MPa); a breaking point at stretching σ_{bps} (MPa); the rigidity providing small reversible deformation of a part (the high module of elasticity) – the elasticity module at stretching E_{ms} (MPa) (stage 6.1.1) [14].

6.2 Stage – definition: loading type "bend" acts on EIP during 1 – 3 sec.? At loading type bend we define: durability or a fluidity limit at a bend / a breaking point σ_{bpb} (MPa); the rigidity providing small reversible deformation of a part (the high module of elasticity) – the elasticity module at a bend E_{meb} (MPa) (stage 6.2.1) [14].

If at the enclosed loading during 1 – 3 sec. – not stretching and not a bend, this compression) means (stage 6.3). At loading type compression we define: durability on a fluidity limit at compression / a breaking point σ_{bpc} (MPa); rigidity (the high module of elasticity) – the elasticity module at compression E_{mec} (MPa) (stage 6.3.1) [14]. Further we pass to a stage 8.

If EIP works at the long enclosed loading at $v_{ot} > 3$ min., then we define loading type: static (stretching or a bend at the usual, or increased temperature); cyclic (a bend, stretching – compression, etc. at the alternate or repeated law of loading change within one cycle) (stage 7).

7 Stage – definition: loading "static" type acts on EIP? Then we define resistance to creep – development of the general deformation (low creep). That is, we determine parameters: creep module $E_{cm(\sigma, T, v)}$ (MPa); the deformation $\varepsilon, \%$ which has developed in parts at application of constant tension σ and temperature T by the moment of time v; the enclosed constant tension σ_{ct} which at a temperature T by the moment of time v causes deformation ε (stage 7.1) [15, 16]. Further we pass to a stage 8.

If loading "static" type doesn't act on EIP, means – cyclic. At type loading cyclic, we define resistance to fatigue failure – maintaining working capacity. That is, we determine parameters: fatigue resistance σ_{fr} (MPa); endurance N_e (stage 7.2) [17]. Further we pass to a stage 8.

After determination of the PM mechanical properties we pass to determination of the PM frictional properties.

8 Stage – definition of friction of EIP concerning other bodies. Transition to a stage 8.1.

If EIP works without increases / decreases in temperatures, without increase in humidity, then we also pass to determination of the PM frictional properties (stage 8). We determine friction of EIP concerning other bodies, namely, parameter – wear coefficient by a grid $K_{wg}, mm^3/(m \cdot sм^3)$; friction coefficient on steel K_{fs} (stage 8.1) [18].

8.2 Stage – determination of the most significant properties – dielectric. It is necessary to define type of electrical loadings action: action of an outside electric field; action of the frequency loadings; action of an electric arc.

That is, for a start we define what electrical loading works if this action of an outside electric field (stage 8.2). Means, we determine parameter – electric strength $E_{es},$ (kV/mm) in case of alternating voltage, the frequency of 50 Hz; unit volume electrical resistance $\rho_V, Om \cdot m$; unit surface electrical resistance ρ_S, Om; inductivity ε_{in} (stage 8.2.1) [19, 20].

If the condition isn't satisfied, then transition to a stage 8.3.

8.3 Stage – definition: frequency loadings act on EIP? If, the condition is satisfied, then it is necessary to find resistance to irreversible dispersion part of the external electromagnetic field energy. Therefore, we define a tangent of dielectric losses angle tg_{δ} (stage 8.3.1) [20 – 23].

If the condition is not satisfied, then electrical load type of EIP – action of an electric arc. We define ability to save insulant properties.

Not to form on a EIP surface of the conductive bridge in case of an electric arc action from an alternating current of small force (10 – 40 mA) and a high tension. That is, we determine parameter – the arc resistance AR (stage 8.4) [24, 25].

After execution of all conditions, a penultimate stage – a choice of a PM processing method taking into account the properties defined earlier (stage 9).

10 The stage – purpose of weight coefficients, the is more than a coefficient, the parameter is more important ($W_1 + W_2 + W_3 + ...W_n = 1$).

11 Stage – the choice of PM taking into account all PM properties.

12 Stage – determination of prime PM cost.

12.1 Stage – definition doesn't exceed the required norms $C_r \leq C_n$? If the condition is satisfied "yes", then PM is chosen rationally. If the condition isn't satisfied, then transition A (the beginning of the scheme). Then process of the PM choice begins from the very beginning won't be yet $C_r \leq C_n$.

The research of PM properties which have been defined also their influence on the choice of material for "insulator" EIP is conducted. Let this EIP work at the increased temperature a long time and is subject to loadings type "stretching". Also this EIP is affected by external electric fields. Data for researches are presented in Table-2.

The materials chosen for the study are the most promising in the field of manufacturing EIP due to chemical, physical, mechanical and technological properties.

1. Ftoroplast-4. He has received the greatest practical application among fluorocarbon polymer because of the exclusive chemical inertness on the relation practically to all hostile environment and unique antifrictional characteristics.

2. Polystyrene block, D – brand D polymer (unpainted) is widely used for parts of high-frequency isolation. Waterproof and in normal conditions has high mechanical durability with temperature increase material gains the increased elasticity.

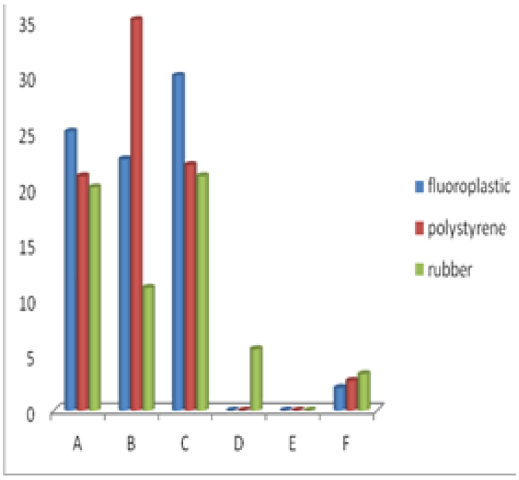
3. Rubbers differ in good electroinsulating properties, high heat stability and frost resistance, big moisture resistance. Rubbers have very low module of elasticity. However their cost is high.

Thus, material, more rational for EIP, from chosen – Ftoroplast-4 that has been defined taking into account weight coefficients which have been so delivered to PM properties (than higher than a coefficient – especially significant he is in this case).

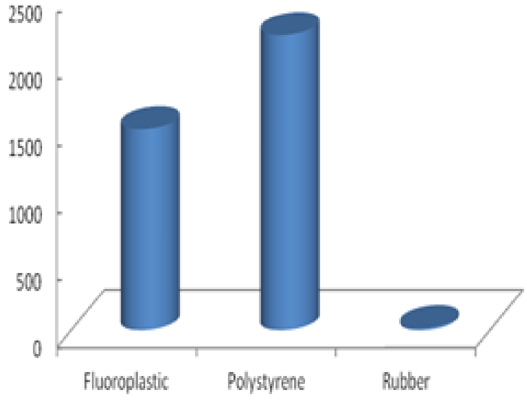
Table 2 Properties of polymeric materials for "insulator" EIP

Material	Fluidity limit at stretching σ_{fs}, MPa	Breaking point σ_{bpc}, MPa	Elasticity module at stretching E_{ms}, MPa	Electric strength E_{es}, кV/mm. With a frequency of 50 Hz	Unit volume electrical resistance ρ_V, Om·sm	Unit surface electrical resistance ρ_S, Om	Inductivity ε_{in}. With a frequency of 50 Hz
Weight coefficients	0.1	0.1	0.14	0.14	0.16	0.16	0.2
Fluoroplastic	25	22.5	1500	30	$1.5\cdot10^{17}$	$1.5\cdot10^{17}$	2.02
Polystyrene Block, D	21	35	2200	22	$1.0\cdot10^{17}$	–	2.65
Rubber	20	11	15	21	$1.0\cdot10^{15}$	$1.0\cdot10^{15}$	3.25

The results of the comparison are presented in the form of graphs in Fig. 1a and Fig. 1b.



a)



b)

Fig. 1. Investigation of the properties of PM:

a) The properties of the PM according to Table-2 without regard E_{ms}

b) The PM property is the modulus of elasticity under tension

IV. Discussion of results

At present, the requirements to improve the quality and improve the accuracy of parts from polymers are constantly increasing, then one of the solving stages this problem is to study the properties of polymers used to make electrical insulation parts in order to select the most significant parameters that must be taken into account in the technological process of molding the part.

The proposed algorithm for choosing a PM for the manufacture of EIP allows us to find a rational material whose properties are important to take into account when designing a forming tool for the production of high-quality polymer EIP.

The algorithm contains a developed sequence of steps to determine the properties of PM parts and to identify important material parameters that directly affect the quality of EIP.

The proposed algorithm for choosing a PM for the manufacture of EIP differs from existing ones in that it takes into account frictional properties and each weight parameter can be weighted to each parameter of the material in order to obtain a more "accurate" result. Also, the algorithm takes into account such conditions as high humidity and low temperature. In general, it makes it possible to determine all the relevant parameters that directly affect the quality of EIPs and with the ability to prevent defects.

Thus, the PM choice is defined:

- electroinsulating properties;
- mechanical durability;
- workability;
- stability of parameters at influence of hostile environment and the changing climatic conditions;
- prime cost.

V. Conclusion

As a result, an algorithm for choosing PM for the manufacture of electrical insulating parts is proposed, which makes it possible to find a rational material whose properties it is important to take into account when designing a forming tool for obtaining a high-quality polymer part.

Based on the generalization of research results in the polymer application field as an electrical insulating material, it is determined that the most important for the choice of material is the temperature interval for the EIP operation.

The factors most influencing the quality of EIP are analyzed and the algorithm for choosing PM for the manufacture of electrical insulating parts is proposed, which will ensure the stability of properties during the molding of the part, as well as during its operation.

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