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Piezoelectric PVDF Cables

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Abstract: Piezoelectrics belong to the group of electromagnetic smart materials and they find an increasingly wider range of applications in practice. The commonly used ceramic piezoelectrics have very good piezoelectric properties but their dimensions are limited by technological considerations. Their another drawback is their brittleness. Polymer piezoelectrics – among which polvinylidene fluoride (PVDF) is characterized by the best properties – do not have such drawbacks.

Most of research reports on the technology of moulding piezoelectrics from PVDF apply to thin films. Whereas in many applications, e.g. monitoring of large areas, piezoelectrics in the form of long lengths of a cable are more suitable.

Keywords: sensors, polvinylidene fluoride, piezoelectric

I. MANUFACTURING

A concentric cable was manufactured by extrusion. The shaping of PVDF's piezoelectric properties involves two major stages:

- the formation of a crystalline beta phase through the mechanical deformation of the amorphous alpha phase produced during extrusion;

- the polarization of the beta phase in a strong electric field to generate piezoelectric properties.

Any technology of the manufacture of piezoelectric cables must take the two stages into account.

The crystalline beta phase is formed by elongating by about 400% the PVDF profile obtained from extrusion. This determines the choice of a material for the cable's inner electrode which is also subjected to about 400% elongation. For this reason the inner electrode is usually made of a highly-plastic semiconducting polymer and fusible metals whose melting point is below the moulding temperature.

A block diagram of a process line for the manufacture of piezoelectric cables is shown in fig. 1.

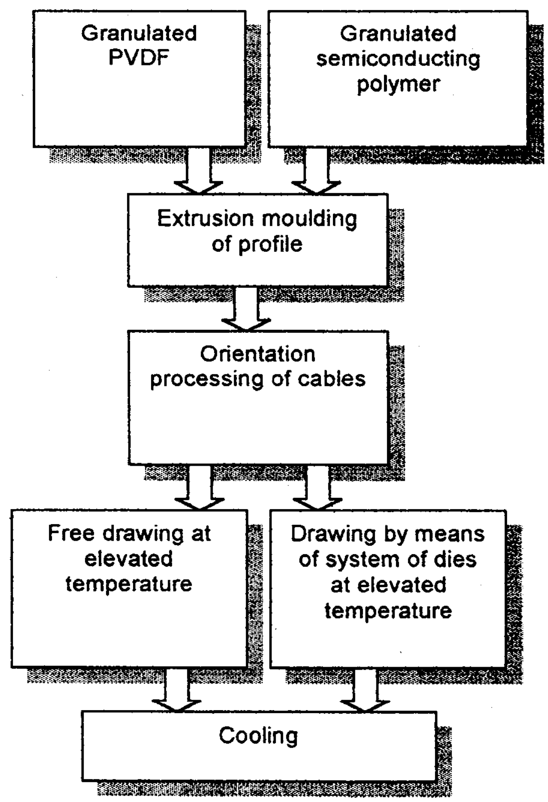

Fig. 1. Technology of manufacturing piezoelectric PVDF cables.

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A manufactured sensor with concentrated structure is shown in fig. 2.

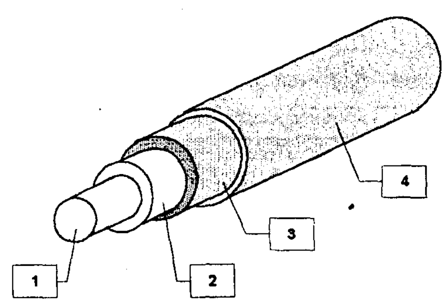

Fig. 2. View of PVDF sensor: 1- inner electrode, 2- piezopolymer layer, 3- outer electrode, 4- sensor`s shield

Drawing ratio D_r determining the formation of beta phase was obtained by drawing the cable through drawholes (dies) whose diameters were calculated from the following relation:

$$D_r = \frac{D_0^2 - d_0^2}{D_1^2 - d_1^2}$$

where: -D_0 – the profile's outside diameter

-d_0 – the inside diameter of PVDF in the profile

D_1 – the profile's outside diameter after orientation

d_1 – the PVDF layer's inside diameter after orientation.

The beta phase content depending on the drawing ratio was controlled by means of an X-ray diffractometer. An exemplary beta phase content versus drawing ratio measurement is shown in fig. 3.

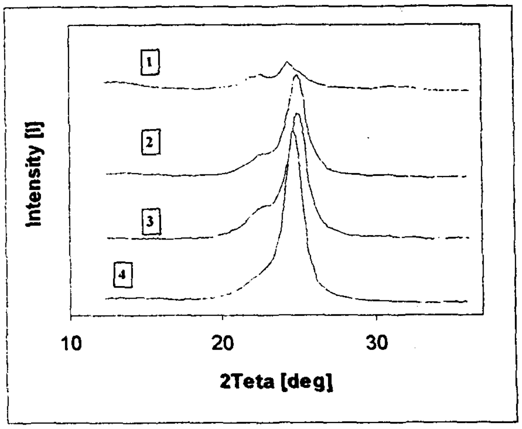

Fig. 3. Change in XRD patterns for PVDF insulation after orientation processing:

1- drawing ratio Dr=2.4

2- drawing ratio Dr=3.6

3- drawing ratio Dr=4.2

4- drawing ratio Dr=4.9

The effect of other parameters on the shaping of piezoelectric properties was controlled in a similar way as above. Fig. 4 shows a diffraction pattern illustrating the effect of the cooling temperature on the beta phase content for a cable moulded at a temperature of 373 K. One can see that the freezing of the formed crystalline beta phase by rapid cooling down to a possibly lowest temperature has an advantageous effect.

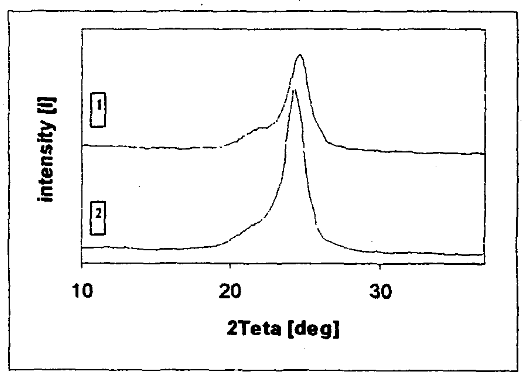

Fig. 4. Comparison of diffraction patterns at similar drawing ratios for PVDF insulations moulded at temperature of 100°C and cooled at:

1- temperature of 278 K

2- temperature of 243 K

The crystalline beta phase in PVDF insulation formed in the process of orientation is unstable at elevated (>353K) temperatures. The outer-electrode coating is usually applied by cold techniques (semiconducting varnish, cold cross-linked semiconducting polymers) which are laborious and inefficient. When the outer electrode was produced from a semiconducting thermoplastic polymer on a conventional extrusion line, the crystalline beta phase content decreased markedly (fig. 5).

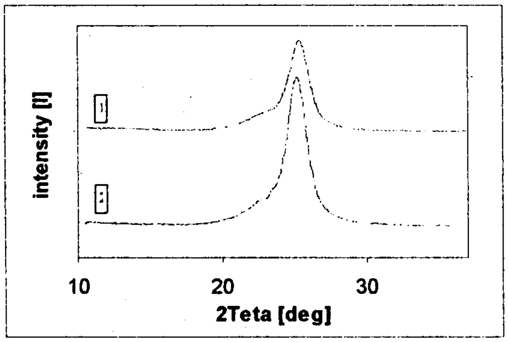

Fig. 5. Change in beta phase content in PVDF insulation caused by technological exposure on conventional process line:

1- insulation after orientation processing

2- insulation after topcoat application

However, when the process line (the crosshead and the cooling system, among others) was modified, an outer semiconducting-thermoplastic electrode with a negligibly changed beta phase content was obtained (fig. 6).

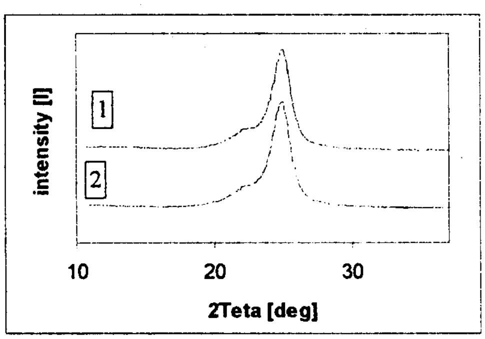

Fig. 6. Change in beta phase content in PVDF insulation caused by technological exposure on modified process line:

1- insulation after orientation processing

2- insulation after topcoat application

To obtain a piezoelectric, the crystalline beta phase must be polarized in a strong electric field.

PVDF is usually polarized by the following methods:

-the thermoelectret method

-the breakdown method

-the plasma method

-the corona method

In the **thermoelectret method** PVDF is exposed to a strong electric field and an elevated temperature simultaneously [1]. After a certain time the temperature is lowered while the electric field in the cable is sustained.

In the **breakdown (strong-field) method** beta PVDF is polarized in a field stronger than 5 MV/cm. A series system of PVDF and other dielectric with lower resistivity is used [2].

In the **plasma method** a plasma produced during a discharge in a rarefied gas constitutes the outer electrode [3]. The cable's central strand constitutes the second electrode. In this method high piezoelectric parameters are obtained in a relatively short time. The disadvantage is that complex apparatus is required.

The **corona method** (polarization by the corona discharge) has been used successfully to polarize piezoelectric films for many years [4]. It can be easily applied to the polarization of concentric piezoelectric cables on a continuous-production line.

Measurement of the piezoelectric ratio d_{3h}

The effectiveness of the above methods was verified by measuring piezoelectric coefficient d_{3h} which specifies the size of a charge induced on a specimen's surface under an applied hydrostatic pressure. The measurements were made using a setup shown in fig. 7.

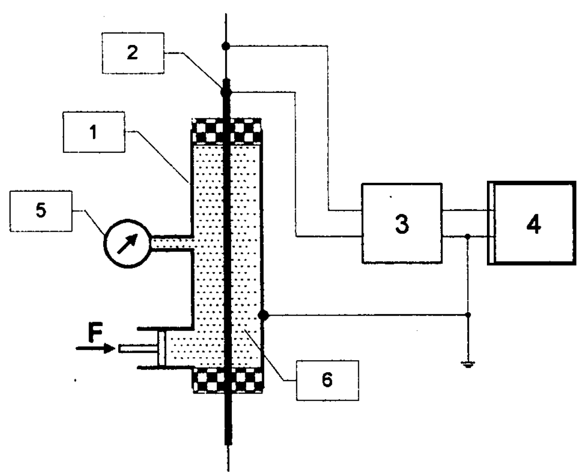

Fig. 7. Diagram of setup for measuring piezoelectric coefficient d_{3h}
1- pressure chamber, 2- PVDF cable, 3- integrator, 4- digital oscilloscope, 5-pressure gauge, 6- water

An exemplary measurement of coefficient d_{3h} versus polarization voltage for a specimen polarized by the corona method is shown in fig. 8.

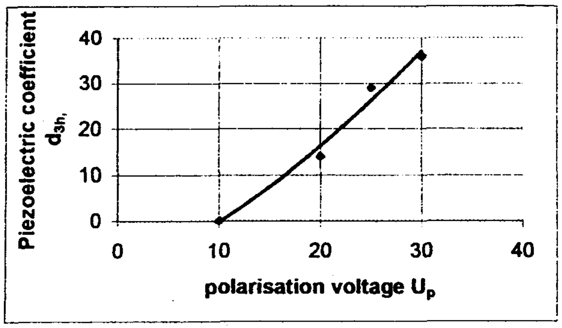

Fig. 8. Piezoelectric coefficient d_{3h} versus applied voltage (cable insulation thickness – 0.2 mm) [2]

The measurements of the piezoelectric properties showed that the low-temperature plasma polarization method yielded the highest values of piezoelectric coefficient d_{3h}.

Tab. 1. d_{3h} values for different kinds of polarization

Kind of polarization	Value of coefficient d_{3h}
Plasma	49
Breakdown	11
Corona	36
Thermoelectret	5

II. POTENTIAL APPLICATIONS

The range of potential practical applications of the presented sensor is wide. It can be applied in all kinds of alarm systems protecting things and premises. Another possible application is street traffic monitoring, i.e. devices measuring the speed and weight of moving vehicles.

Among medical applications it is worth to mention a newborn infant breathing monitor and a patient stillness detecting device.

III. CONCLUSIONS

The research on the development of a manufacturing technology has led to a simple and efficient method of endowing the PVDF polymer with oriented structure by means of drawing dies. The thermal conditions of orientation processing have been optimized to obtain a high beta phase content. The technology of applying the outer piezoelectric-cable electrode by the hot method, which simplifies considerably the process of manufacturing the piezoelectric cable, has been mastered.

Thanks to its structure the cable can operate in difficult environmental conditions, e.g. under water or under a layer of soil. The sensor is extremely resistant to chemical attack and to mechanical impacts. Another equally important advantage of the sensor is its very wide transmission band which for the acoustic wave extends up to the frequency of about 1 GHz. The linear form of the sensor makes the latter suitable for monitoring large industrial, military and other facilities. Thanks to the sensor's considerable flexibility, its shape can be changed and fitted to the shape of an area to be protected.

Acknowledgment

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