

Development of Heat-Resistant Triple-Insulated Winding Wire "TEX-F"

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ABSTRACT A triple-insulated winding wire with enhanced heat resistance, TEX-F, has been developed enabling further downsizing and performance upgrading of transformers for switching mode power supplies. In terms of thermal class, TEX-F belongs to the class F of 155°C, while conventional TEX-E belongs to the class E of 120°C. The available conductor sizes and insulation thickness are the same as for the conventional TEX-E, so that TEX-F winding wires with conductor sizes ranging from 0.2 mm to 1.0 mm covered with a thin triple-insulation layer of 100 μm (about 33 μm per layer) can be manufactured. As for safety standards, TEX-F meets IEC60950 like TEX-E, having acquired certification from a number of countries.

Moreover, unlike TEX-E, TEX-F is provided with the superior property in high-frequency V-t characteristics. This gives the wire substantial long-term resistance against corona discharge that is caused by excessive voltages on transformers, thus improving the reliability of transformers.

1. INTRODUCTION

Along with the downsizing of electric and electronic equipment in recent years, power supplies in such equipment are required increasingly to be small in size. The mainstream for power supplies is switching mode type, in which switching devices are used to raise the frequency of the input, so that the winding number of the transformer is reduced thus resulting in downsizing.

We had developed TEX-E, a triple-insulated winding wire for switching mode power supplies, which has been extensively accepted and used worldwide. Meanwhile, the heat generated in transformers has increased recently associated with the growing need for downsizing, resulting in users' requirements for a new triple-insulated winding wire with higher thermal class.

Moreover, the electrical characteristics of winding wires in the high-frequency band where these wires are actually used for switching mode transformers were not very well investigated. Accordingly, we have explored the V-t characteristics of winding wires in the high-frequency band using a high-frequency rectangular pulse generator, thereby succeeding in establishing a resin composition that significantly improves the performance.

This report describes the development process of TEX-F, a triple-insulated winding wire with enhanced heat resistance and upgraded high-frequency V-t characteristics.

2. IEC60950 AND TRIPLE-INSULATED WINDING WIRES

First, explanations will be given as to how switching mode transformers are constrained in terms of safety standards and how and where triple-insulated winding wires are used.

One of the most important international standards concerning switching mode transformers is IEC60950 of the International Electrotechnical Commission, a standard on Safety of Information Technology Equipment.

Major requirements of the standard for the transformers are as follows:

- 1) Solvent-based enamel coatings are not considered to be insulation.
- 2) Supplementary insulation or reinforced insulation specified IEC60950 having a minimum distance through insulation of 0.4 mm shall be provided between the primary and secondary windings.
- 3) Reinforced insulation comprises three layers of material for which all combinations of two layers together shall pass the electric strength test. (The insulation thickness is not specified)
- 4) A specified length of creepage distance --the shortest path between two conductive parts, or between a conductive part and the bounding surface of the equipment, measured along the surface of the insulation-- must be secured between the primary and secondary windings.

To comply with this standard, switching mode power supplies using conventional enameled wires have been designed to provide, as shown in Figure 1, an interleaved insulation tape with three layers in addition to barrier tapes securing a specified creepage distance. As can be seen,

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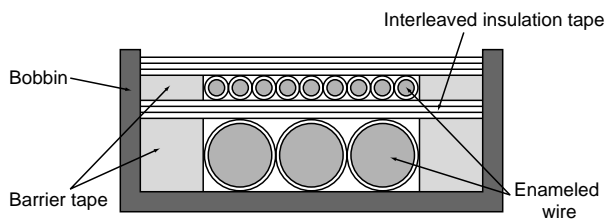


Figure 1 Structure of conventional transformers.

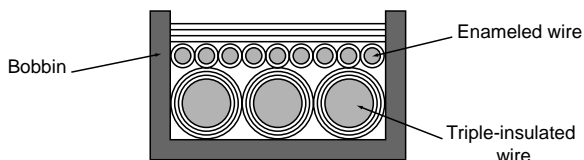


Figure 2 Structure of transformers using triple-insulated winding wire.

this structure makes downsizing and cost reduction of transformers difficult.

Triple-insulated winding wire has been devised, therefore, in which the wire itself is provided with the function of reinforced insulation. Such a winding wire also is stipulated in IEC60950, so that only those that meet the standard are qualified for certification of triple-insulation.

Use of triple-insulated winding wires can modify the structure of transformers as shown in Figure 2, i.e., the interleaved insulation tape between the primary and secondary windings is eliminated, and insertion of barrier tape is no longer necessary because the conductor is entirely covered with the reinforced insulation thus resulting in no emergence of creepage distance. The modified structure enables downsizing of the transformer in addition to reduction of the process in wrapping of the interleaved insulation tape and insertion of the barrier tape.

Based on such concept Furukawa Electric has developed the TEX-E triple-insulated winding wire, which is supplied nowadays to a number of countries around the world.

3. DEVELOPMENT OF TEX-F

Recently, some of the transformer products are required to reduce their size further, resulting in such structures that are high in heat generation or difficult to dissipate the heat. Thus, the temperature in the equipment in some cases rises from 120°C, which can be dealt with the class-E wire, to 130°C (class B) or 155°C (class F).

3.1 Development Targets

We have decided therefore to develop a heat-resistant winding wire TEX-F with upgraded heat resistance, aiming at achieving the following development targets while maintaining the advantages of TEX-E.

- 1) To acquire the certification of safety standards from selected countries
- 2) To withstand a voltage requirement of 3 kV for 1

Table 1 Comparison of manufacturing methods of TEX-F.

Evaluation term and importance	Manufacturing method				
	Tape wrapping	Enamel coating	Powder coating	Extrusion	
Safety standard	◎	○	×	△	○
Withstand voltage	○	○	△	×	○
Windability	○	×	◎	△	○
Cost	○	×	△	○	○
Overall judgement		×	×	×	◎

◎: Excellent ○: Good △: Fair ×: Failure

min, as required by safety standards, with a nominal insulation thickness of 100 μm

- 3) To have an adequate level of windability for coil winding with a nominal insulation thickness of 100 μm
- 4) To have the thermal class F, i.e., 155°C

3.2 Manufacturing Method

Four wire manufacturing methods of tape wrapping, enamel coating, powder coating, and extrusion were studied in comparison at the development of TEX-E. The same evaluation terms were used to select the manufacturing method of the TEX-F winding wire with enhanced heat resistance, and the results are shown in Table 1.

First, enamel coating was regarded unsuitable from the standpoint of safety because, as mentioned before, IEC60950 does not consider enamel coating as insulation. In addition, both enamel coating and powder coating were judged to be technically difficult in achieving the withstand voltage characteristics of 3 kV for 1 min with an insulation thickness of 100 μm, securely along the wire length, as required by one of the development targets.

Thus, we had two options of tape wrapping and extrusion, which were supposed to result in not much difference in terms of electrical characteristics. In terms of windability, however, tape wrapping raises concern about irregularities at the lapped tape in addition to lifts of tape when the wire is worked by bending. Moreover, in terms of manufacturing costs, tape wrapping seems to be inadequate for high-speed manufacturing due to the limit of line speed. In particular, shorter wrapping pitches are needed for smaller sizes, raising the cost further.

Consequently, we have decided to investigate the manufacturing method based on extrusion, the same as before, in developing the TEX-F triple-insulated winding wire with enhanced heat resistance.

3.3 Insulation Resin

Both modified polyester and polyamide, which were selected as the insulation resin of TEX-E, were unsuitable for the current development in which the thermal class targeted at was over 130°C. Using commercially available heat-resistant resins, therefore, we carried out extrusion experiments to make a comparative study taking into consideration the following terms:

- Wire performance (electric characteristics, heat resistance, flexibility, appearance, and others)
- Extrudability (workability, ease of high-speed extru-

Table 2 Comparison of insulation resins for TEX-F.

Resin	Heat-resistant polyester (A)	Heat-resistant polyester (B)	Sulfone (A)	Sulfone (B)	Sulfone (C)	Heat-resistant polyamide	Fluorocarbon polymer
Electrical characteristics	○	○	○	△	○	○	○
Heat resistance	×	△	○	○	○	△	○
Flexibility	○	×	○	○	○	○	○
Appearance	○	○	△	○	○	○	○
Workability	○	○	○	△	○	△	×
High-speed extrudability	○	○	△	×	△	×	×
Extrusion temperature	280°C	350°C	370°C	400°C	370°C	340°C	300°C
Resin cost	○	○	△	△	△	△	×
Overall judgement	×	×	△	×	○	×	×

○ : Good △: Fair ×: Failure

sion, and others)

- Resin cost

Table 2 shows comparisons of heat-resistant resins studied at this time including:

- Heat-resistant polyester group
- Sulfone group
- Heat-resistant polyamide group
- Fluorocarbon polymer group

Two types of heat-resistant polyester group were studied, but one of them resulted in poor heat resistance and the other insufficient flexibility of the wire.

Next, three types of sulfone group were studied. Every resin had a high value of viscosity, raising concern about manufacturing of small sized wires. Besides, the resin cost was rather high. However, practically no problem was presented in terms of workability despite their extrusion temperatures that were slightly high, and it was entirely feasible to conduct high-speed extrusion with all the resins excluding one type. Among these, Sulfone (C) was confirmed to be superior in appearance when it was extruded to form wires.

Then a type of heat-resistant polyamide group was studied. It was found that the resin was high in viscosity, raising problems of high-speed extrusion.

Lastly a fluorocarbon polymer group was studied. Although it was proved that the resin caused no problem with regard to wire performance including electrical characteristics, it emitted decomposed fluoric gases resulting in inferior workability; it had poor appearance when extruded at high speed; and it created cost problems because the resin was considerably expensive.

As the result of the study, we concluded to select Sulfone (C) as the insulation resin for the TEX-F heat-resistant triple-insulated winding wire.

Figure 3 shows the heat resistance --determined in accordance with IEC60172-- of the TEX-F triple-insulated winding wire manufactured using Sulfone (C) in comparison with that of TEX-E. It has thus been confirmed that the high-temperature service life --converted to 20000 hours of service-- of TEX-F is well over the class F of 155°C.

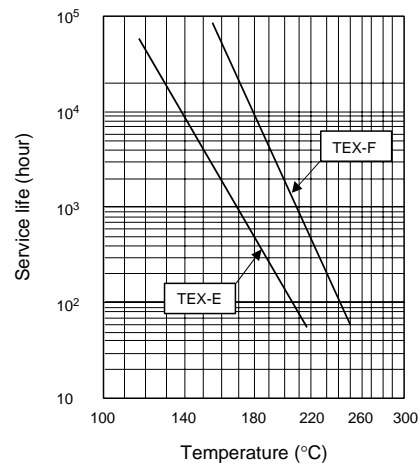


Figure 3 High-temperature service life of TEX-E and TEX-F.

4. IMPROVEMENT IN HIGH-FREQUENCY CHARACTERISTICS

Heretofore, the characteristics of TEX-E under conditions of use in switching mode power supplies have not been carefully studied, including in particular, its high-frequency electrical characteristics. In view of this, we have measured the partial discharge inception voltage and the V-t characteristics of TEX-E as well as those of TEX-F using a high-frequency rectangular pulse generator shown in Photo 1. V-t characteristics refer to the relationship between applied voltage (V) and duration of voltage application (t) until breakdown occurs.

Table 3 shows the measured results of partial discharge inception voltages at high frequency using rectangular pulses for polyurethane wire (UEW), TEX-E, and TEX-F. It can be seen that TEX-F shows a little lower result than TEX-E regarding the partial discharge inception voltage at high frequency, i.e., 10 kHz in this case. This may be accounted for by a theory that the partial discharge inception voltage is proportional to the insulation distance and inversely proportional to the relative permittivity of the resin used, reflecting the fact that the relative permittivity, i.e., 3.5 of Sulfone (C) is slightly larger than that, i.e., 3.3 of modified polyester/polyimide used for the insulation of TEX-E.

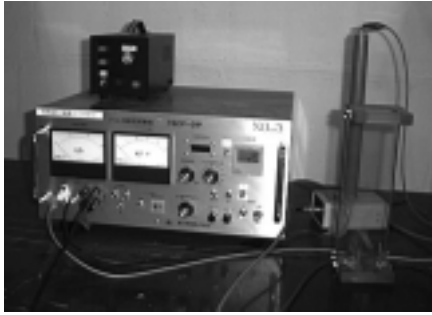


Photo 1 Measuring equipment for high-frequency V-t characteristics.

Table 3 Comparison of partial discharge inception voltage of UEW, TEX-E, and TEX-F.

Sample	1-UEW / 1-UEW	TEX-E / TEX-E	TEX-F / TEX-F
Partial discharge inception voltage (kV), at 10 kHz, 8 μs pulse width	1.66	3.34	3.20

Table 4 High-frequency V-t characteristics of TEX-E and TEX-F.

Sample	TEX-E / TEX-E	TEX-F / TEX-F
Measuring conditions		
High-frequency V-t (min), 20 kHz, 10 μs, 3.0 kV	100	430
High-frequency V-t (min), 20 kHz, 10 μs, 3.5 kV	5	63

Next, Table 4 shows the measured results of V-t characteristics using rectangular pulses. It has been confirmed that, according to Table 4, TEX-E suffers breakdown in a relatively short time at high-voltage ranges where partial discharge occurs, and that TEX-F developed at this time outperforms TEX-E in this regard.

It is known that addition of inorganic filler to the coating improves the high-frequency V-t characteristics, so that we investigated the effects of inorganic filler addition to the insulation of TEX-F. We chose an inorganic filler that is superior in mutual solubility with Sulfone (C) and tends to cause little degradation of electrical characteristics as well as flexibility.

Figure 4 shows the change in the high-frequency V-t characteristics due to the addition of the inorganic filler, from which the V-t characteristics are seen to have substantially improved by the addition of the filler.

The reasons for this remarkable phenomenon may be explained as follows.

- Phenomenon: Sulfone (C) with the high heat resistance of insulation is superior in high-frequency V-t characteristics.

Reason: It is supposed that the current concentrates on the conductor surface at high frequencies raising the wire

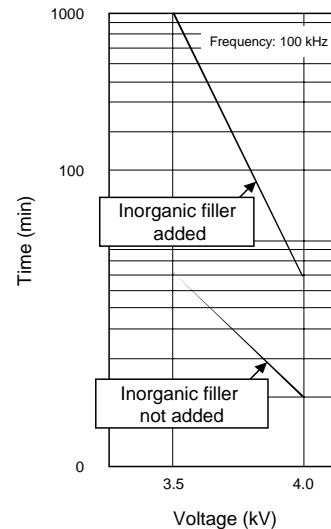


Figure 4 Improvement of high-frequency V-t characteristics of TEX-F by the addition of inorganic filler.

temperature, and the high heat resistance is effective in improving the V-t characteristics.

- Phenomenon: The addition of inorganic filler improves the high-frequency V-t characteristics.

Reason: Electrons attack the insulation when discharge occurs, abrading the insulation. It is likely that the attack is relieved by the inorganic filler.

5. CHARACTERISTICS

Table 5 compares the major wire characteristics for TEX-F and TEX-E of conventional type. As shown, it is seen that TEX-F is superior to TEX-E with regard to insulation breakdown voltage and abrasion resistance. Moreover, it is confirmed that TEX-F passes Annex U and Modified Annex C of IEC60950 that specify safety standards even under the condition of class F. In terms of solderability, however, the heat-resistant resin used in TEX-F does not permit direct soldering, necessitating removal of the insulation layer. In addition, it is known as one of the shortcomings of the resin that Sulfone (C) suffers cracking against some resins and solvents, and thus is unsuitable for use with styrene resins in particular.

Table 6 shows the compatibility of TEX-F with commercially available varnishes. As shown in the Table, TEX-F is seen to be insufficiently compatible with impregnating varnishes based on styrene, while its compatibility with the varnishes based on water-soluble solvents and gasolines virtually creates no problems presenting no degradation in characteristics. In any case, it seems that the compatibility has to be confirmed when an impregnating varnish is to be used with TEX-F.

Table 5 Comparison of wire characteristics for TEX-F and TEX-E.

Item	TEX-E	TEX-F
Conductor diameter (mm)	0.400	0.400
Overall diameter (mm)	0.600	0.600
Insulation thickness (mm)	0.100	0.100
Breakdown voltage (kV)	23.4	28.6
Solderability at 420°C (sec)	3.0	Unsolderable
Spark test at 3 kV (count/30 m)	0, 0, 0	0, 0, 0
Resistance to softening (°C)	231	260
Unidirectional scrape test (N)	19.31	20.87
Reciprocating scrape test (times)	285	1000<
Static friction coefficient	0.125	0.250
Chemical resistance (pencil hardness)		
Xylene	3H	H
Styrene monomer	3H	NG
Annex U.2.1	○	○
Annex U.2.2	○	○
Annex U.2.3, E-class	○	○
Annex U.2.3, B-class	△	○
Annex U.2.3, F-class	×	○
Annex U.2.4	○	○
Modified Annex C, E-class	○	○
Modified Annex C, B-class	×	○
Modified Annex C, F-class	×	○

○ : Good △ : Fair × : Failure

Table 6 Compatibility of TEX-F with impregnating varnishes.

Main insulating material	Solvent	Residual breakdown voltage (%)			
		No heating	130°C × 7 days	155°C × 7 days	180°C × 7 days
Original	-	100	107	101	104
Polyester group	Water	105	95	92	99
Alkyd group	Gasoline	110	106	112	78
Alkyd group	Xylene	80	90	90	90
Unsaturated polyester / Styrene	Solventless	37	30	24	13

6. ACQUISITION OF SAFETY CERTIFICATION

TEX-F succeeded in acquiring certification of safety standards from a number of countries as shown in Table 7. It should be noted that the certified rating temperature is class A of 105°C for the UL, and is class F of 155°C for other organizations. The UL stipulates that the wire as well as the bobbin material, insulation tape, and impregnating varnish have to be approved according to UL1446 independently as an insulation system constituted by the materials, when they are used at an ambient temperature exceeding class A of 105°C. Meanwhile, the certified working voltage is 700 V_{rms} or 1000 V_{peak} for VDE, and is 1000 V_{rms} for other organizations.

Table 7 List of safety codes that certify TEX-F.

Organization	Country	Acquired standards
UL	U.S.A.	UL1950
CSA	Canada	IEC60950 IEC60065 CSA C22.2 No.1 950
VDE	Germany	IEC60950 EN60950 IEC60065 DIN VDE 0860 HD 195 S6
TUV	Germany	IEC60950 DIN EN 60950 VDE 0805 IEC60065 DIN EN 60065 VDE 0860
BSI	U.K.	IEC60950 BS EN60950 IEC60065 BS EN60065
NEMKO	Norway	IEC60950 IEC60065

7. SUMMARY

We have developed a triple-insulated winding wire TEX-F with enhanced heat resistance (class F of 155°C), and have succeeded in acquiring safety standard certification from a number of countries. TEX-F has been successful in improving the high-frequency V-t characteristics, so that the wire is likely to advance the safety of transformers.

Remaining issues that we plan to address in future are acquisition of UL1446 for insulation systems including the bobbin material and insulation tape, in addition to development of a new wire with improved performance in solvent resistance and solderability.

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