High Voltage DC Testing on Enamelled Copper Wires

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Abstract—**Copper wire, cable, and optical fibre industry customers consistently demand high quality products. The need for quality control has led to the implementation of automatic, online surface inspection systems, which have significantly improved the monitoring of surface quality. International competition among copper wire suppliers, in particular, in critical markets such as the electrical appliance industry has caused an increase in demand for automatic surface inspection equipment and has spurred the development of systems with higher levels of performance. Earlier techniques employed cause permanent damage to the wire which are not preferred. This calls for the need of a non-destructive method of testing the insulation faults.**

Keywords—Copper, defects, Enamel, fault current, High voltage, Labview, pulley

I. INTRODUCTION

Enamelled copper wire, also called "magnet wire," is widely used all over the world in electrical equipments. The difference between the enamelled copper wire and regular wire is in the insulation surrounding the wire. Normal copper wire is insulated by wrapping it in thick rubber. Enamelled copper wire is insulated by coating it with enamel. It is primarily used in three types of applications. It is used, in transformers to transform one kind of electrical energy into other kinds. It is used in motors to transform electrical energy into mechanical energy. It is also used in generators to transform mechanical energy into electrical energy.

One of the primary properties that make enamelled copper wire desirable for these applications is the enamelling insulation. Transformers, motors and generators are all machines based on the coil, which is a device that generates magnetic fields and electrical currents using large coils of wire [1]. The smaller these devices are, the stronger they are. Because enamelled copper wire is insulated by a thin coat of copper instead a thick sleeve of rubber, it takes up less space, and so can make more effective coils.

Enamelled copper wire is also so widely used in these devices because of its conductivity. Wire is meant to carry electrical currents. All materials resist the flow of electrical currents to some extent or other, so the best material to make wires out of would be the most electrically conductive, least electrically resistant material available. Copper has less resistance than almost any other material. This means that generators using copper wire will produce more electricity than generators using most other substances. Motors made of it will produce more motion. Transformers made of it will lose less energy.

The third feature of enamelled copper wire that makes it so attractive for use in these devices is its resistance to corrosion. Almost all metals rust, but some rust more quickly than others. While silver is an excellent conductor, it rusts far too quickly to be of any value in electrical equipment. Due to its high resistance to corrosion, copper is the material of choice for use in electrical circuits, as it will last a long time.

Enamelled copper wire comes in the same range of gauges that ordinary wire does, from about 5 AWG to about 40 AWG. "AWG" stands for American wire gauge. These gauges correspond to diameters of 182 thousandths of an inch to three thousandths of an inch [3].

The enamel insulation of magnet wire is formed of a chemical called polyimide. This is class H insulation, as rated by the Institute of Electrical and Electronics Engineers. This is the highest possible rating, and means that the wire can withstand temperatures of 356 degrees Fahrenheit for at least 20,000 hours. This makes enamelled copper wire capable of carrying more current than wires of the same size insulated with anything else.

Insulated wires are produced in commercial quantities from bare copper or aluminium wire by applying the liquid resin enamel to the bare wire and curing the resin enamel coating by passing the wire through an enamelling oven. To obtain the desired insulation build, a preselected number of passes are made through the enamelling oven. Fine copper wires leaves the enamelling oven at speeds ranging from 80 to 200 feet per second, and as many as 20 strands of wire may be run through the enamelling oven. Although it is extremely desirable that insulation coating of the wire be entirely free of any faults, this has not been readily achieved in the commercial production. At best, manufacturers assure their customers that any particular wire produced by them will have no more than a specified number of faults in the insulation per hundred feet of it. In order to make such a representation, the manufacturer must continuously test the wire to determine the number of discontinuities in the insulation coating. The testing is normally carried out as the enamel coated wire leaves the enamelling oven but before the enamel coated wire is wound on spools.

II. DEVICE PRINCIPLE

The principle of High voltage continuity test is shown in fig.1.the enamelled wire specimen with the conductor earthed is pulled over a "V" grooved electrode (pulley) fixed on Bakelite sheet at a constant speed. A d.c. test voltage controlled to precision of +/- 10% is applied between the electrode and earth as shown in figure. A shielded cable was used to connect the high voltage source to the pick-up pulleys. Any faults in the insulation of the wire are detected by measuring the current discharge in the conductor and numbers of faults are recorded on a counter. Theoretically speaking, insulation material does not carry any current but practically it carries negligible current. The threshold establishment is necessary for rejection of copper wire on the basis of enamel coating thickness, due to flaws in manufacturing. The maximum current that the bare conductor can carry at the supplied high voltage is set as maximum safe value for fault current. Fault current is limited to few micro amps through internal series resistance [3].

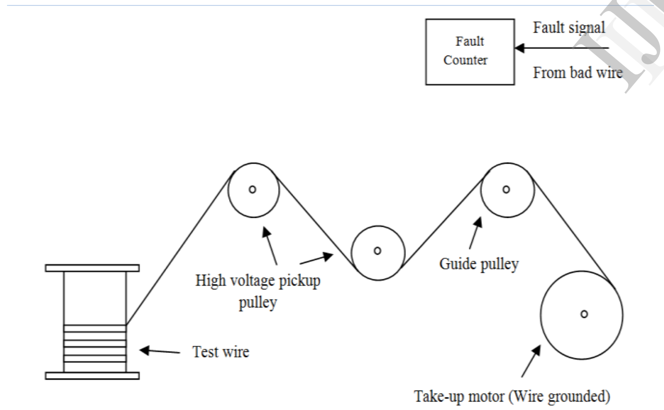


Fig. 1. Schematic diagram

The length of tested enamel led wires is 30m.During test, the test velocity pulley is used to test the operation velocity of enamelled wires, according to it, controls the velocity of spin of the coiling wires pulley, in order to make enamelled wires operate at a certain velocity.

III. CHARACTERIZATION OF FAULTS

Based on morphology and origins of continuity faults, they are broadly classified as follows:

TABLE. 1. DEFECT TYPES AND CAUSES

Type	*Causes*
Copper Rod Defects	-cracks -oxides -slivers
Wire Drawing Damage	Scratching and scraping Compacted copper fines Mechanical damage Slivers
Bare Wire Contamination	Copper fines Surface oxides oil/grease/lubricant
Enamel Film Damage	Mechanical damage cavitations tracking Peel-back
Airborne Contaminants	Burnt enamel Copper oxide Outside enamelling process
Enamelling defects	air bubbles Gel particles pinholes

There are to individual adjustable levels of detector threshold. The two levels make it possible to collect the faults into groups for pin holes and weak spots.

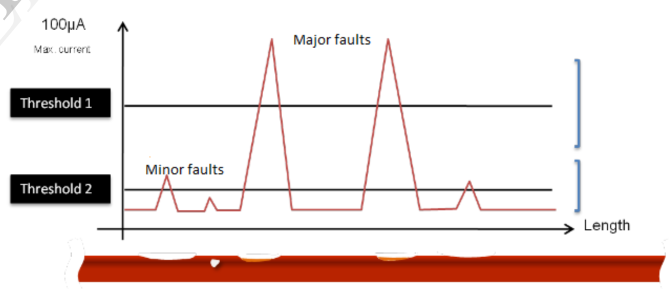


Fig. 2. A sample of fault current with time

IV. MATHEMATICAL ANALYSIS

There is a need therefore for an improved testing apparatus for continuously detecting faults in the insulation coating on copper wire that would only draw current significantly less than 100 micro-amperes when a fault occurs. Preferably, this maximum current should be in the order of 25 micro-amperes or less.

The primary purpose of wire insulation is to provide turn-to-turn or layer-to-layer insulation; as such, the voltages involved are relatively low regardless of the overall component rating. Like other wires, copper wire is classified by diameter (AWG number or SWG) or area (square millimetres), temperature class and insulation class.

Breakdown voltage depends on the thickness of the covering, which can be of 3 types: Grade 1, Grade 2 and Grade 3[1]. Higher grades have thicker insulation and thus higher breakdown voltages.

The temperature class indicates the temperature of the wire where it has a 20,000 hour service life. At lower temperatures the service life of the wire is longer (about a factor 2 for every 10 °C lower temperature). The breakdown voltage of an insulation material depends mainly on the thickness of the insulation, the bare wire diameter, the application temperature of the coil and the type of enamel [1].

The average breakdown voltage can be calculated as,

$D_s = t \text{ x } V\mu$ [Volt], (1)

D_s : breakdown voltage

T: increase due to insulation

$T=d_a-d_{nom}$; wire diameter with and without insulation

$V_{\mu m}$ = volts per micron insulation (dependent on type of insulation)

The insulation material for the wire under test is polyimide coat.

Example:

Test with cylindrical electrode (round wire)

D_{nom}=0.071mm (bare wire nominal diameter)

D_a=0.083mm (wire with coating)

$t=d_a – d_{nom}$ =0.083-0.071 = 0.012mm =12µm

(Thickness of insulation between wires)

Vµ =205V/µm, therefore,

Ds=12µ x 205V/µ =2,460V

Ohm's Law

When an electric potential V is applied across a material, a current of magnitude, I flow. The current I is proportional to V, according to Ohm's law:

$I = V/R$ (2)

Where, R is the electrical resistance. R depends on the intrinsic resistivity ρ of the material and on the geometry (length l and area A through which the current passes).

$R = \rho\, l/A$ (3)

The electrical resistance of an insulting material, like that of conductor is the resistance offered by the conducting path to the passage of current. Insulting materials are very poor conductors when dry, so that resistance values tend to be in mega-ohms. Also, in the case of insulators, the thickness of the film may be constant, but it is poorly defined-typically conduction takes place in the top layers of the surface and in any contamination or moisture on top of it.

The electrical conductivity is the inverse of the resistivity:

$\rho=1/\sigma$ (4)

Resistance depends on a number of factors, including temperature, humidity, moisture content, applied voltage and the duration of voltage application. Comparing or interpreting data is difficult unless the test is controlled and defined, especially when a specimen is drying out after subjects to moist or humid conditions. Results can be particularly affected by surface wetting or contamination, which greatly reduces surface resistivity.

Dielectric strength

All insulting materials fail t some level of applied voltage, and 'dielectric strength is the voltage material can withstand before breakdown occurs [1]. Dielectric strength is measured through the thickness of the material (taking care to void surface defects) and is normally expressed s a voltage gradient (volts per unit length).The voltage gradient is much higher for very thin test pieces (<100µm thick) than for thicker sections. The value of dielectric strength for a specimen is also influenced by its temperature and ambient humidity, by any voids or foreign materials in the specimen, and by the conditions of test, so that it is often difficult to compare data from different sources.

V. LABVIEW SIMULATION

Main VI

Fig. 3.1a shows the main VI-front panel and block diagram..The front panel window is the user interface for the VI. It contains controls and indicators, which are the interactive input and output terminals of the VI respectively. The last fault current and number of fault terminals indicate the current monitored for the last measurement taken and number of faults detected respectively. The FAULT LED glows when a fault is detected and is indicated as 'Fault detected' in the fault description terminal. Also, RELAY ACTIVE LED glows when the current limit exceeds its upper limit.

The graphical representation clearly indicates the current monitored with its sudden rise when a fault is detected. To the right side of the front panel are the icons 'START' to start the process, 'SETTINGS' icon which allows the user to define upper and lower current limits of the wire, 'REPORT' icon to generate complete report of the wire under test and ‘EXIT’ icon to exit from the process.

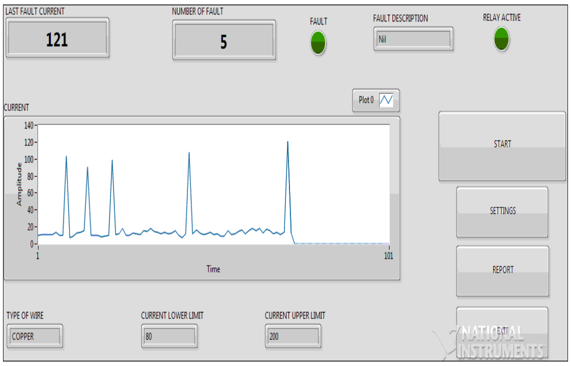


Fig. 3.1a. Front panel window of Main VI

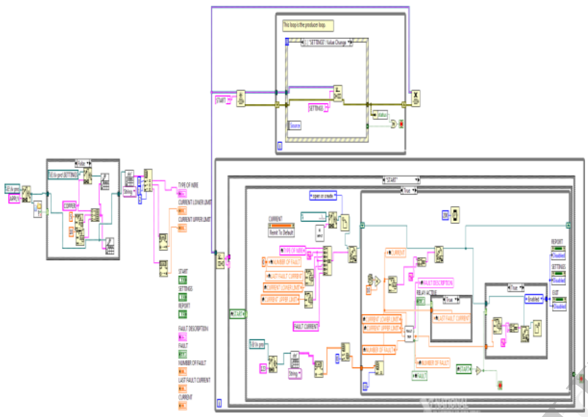


Fig. 3.1b. Block diagram window of main VI

The block diagram window contains the graphical source code which includes graphical representations of functions to control the front panel objects .Front panel objects appear as terminals on the block diagram.

Settings

When the ‘SETTINGS’ icon in the main VI is pressed, the sub VI for it is opened. Here, the user can choose the type of wire, set upper and lower current limits and save the values from the combo list provided for the respective terminals and also, save the values for future access.

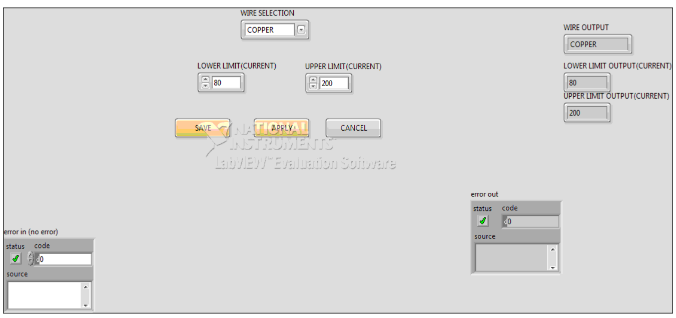


Fig. 3.2a. Front panel window of Settings subVI

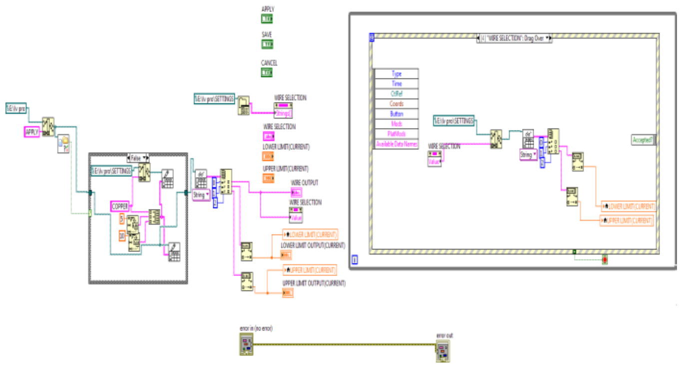


Fig. 3.2b. Block diagram window of Settings sub-VI

Fault and trip

The front panel window shown below for ‘fault and trip’ sub VI indicates the current sensed by the sensor, its upper and lower limit set values, previous and present count and fault detection status. Also, LEDs are provided to indicate fault detection and relay trip.

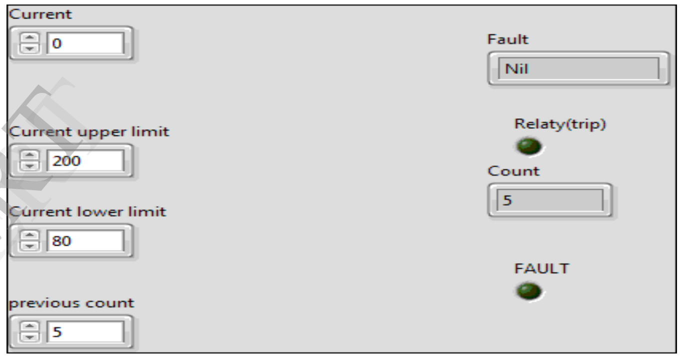


Fig. 3.3a. Front panel window of Fault and trip subVI

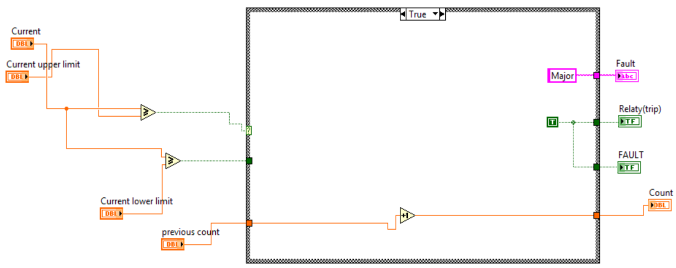


Fig. 3.3b. Block diagram window of Fault and trip sub-VI

Report Generate

On pressing the ‘REPORT’ icon on the main VI, the control jumps over to the Report sub VI were the user is asked to enter the wire ID and press the SEARCH button. If the file name exist, GENERATE REPORT icon becomes active allowing the user to generate a complete report on the wire under test which include graphical plots, number of faults detected, current limits and so on of the wire ID entered, in pdf file format. Otherwise, ‘FILE DOESNOT EXIST’ is displayed.

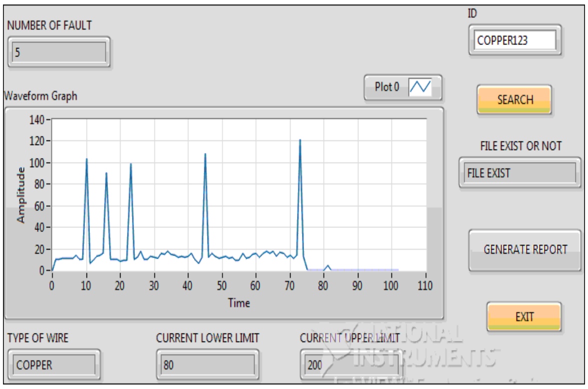


Fig. 3.4a. Front panel window of Report sub-VI

The block diagram controlling the front panel functions of REPORT sub VI is shown below.

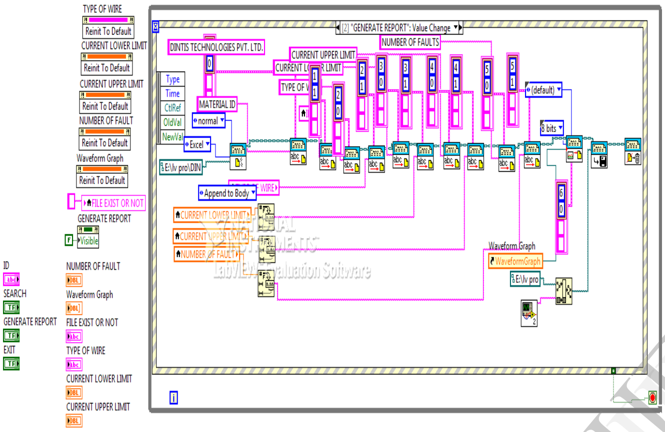


Fig. 3.4b. Block diagram window of Report sub-VI

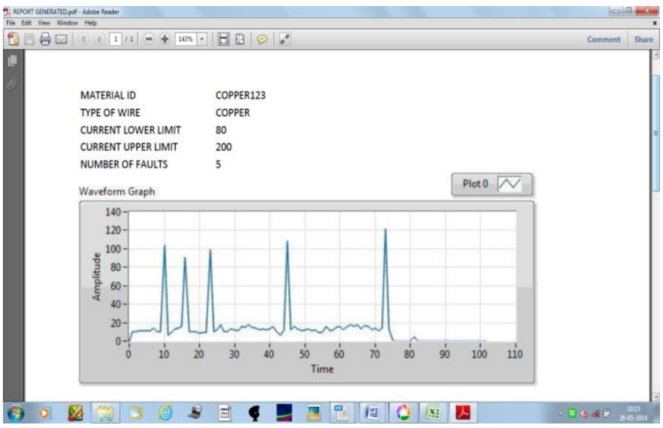
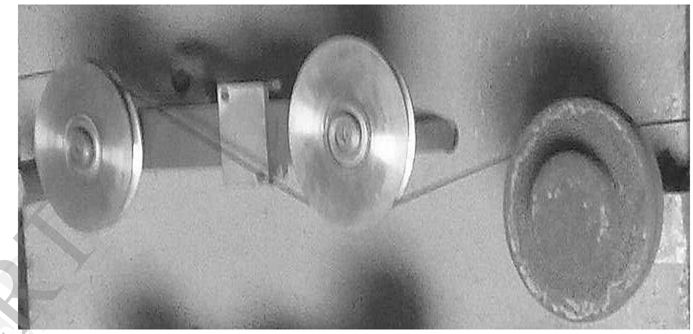


Fig. 3.5. A sample report generated in pdf format

VI. RESULT ANALYSIS

Voltage (KV)	Fault current(µA)	Series resistance (MΩ)	Fault resistance (MΩ)
4500	19.2	170	75
4000	17.9	160	75
3500	16.5	140	75
3000	15.4	120	75
2500	14.3	100	75
2000	12.9	80	75
1500	11.1	60	75
1000	8.7	40	75
750	7.1	30	75
500	5.3	20	75
350	3.9	14	75

VII. PROJECT HARDWARE



VIII. CONCLUSION

The proposed test method is a non-destructive method of testing defects in insulation co on copper wires. The method has a major advantage of dc over ac voltage as the latter may introduce distortions leading to poor detection. Another advantage is the use of high frequency decision device-Arduino Due operating at 84MHz with low delay time.

The method for determining the location of a defect site in the wire comprises injecting into the drive end of the pulley, a high voltage pulse having sufficient voltage to cause an electrical breakdown at the defect site. The electrical breakdown, in turn, generates current pulses which propagate away from the defect site along the wire to the ground. The pulses generated by the electrical breakdown at the defect site can be detected by sensor. The location of the defect site can be determined from the difference in arrival times between the detected pulse and speed of the wire. The wire passes over two 'V' grooved and one guided pulleys fitted at some distance apart from each other on a non conductive surface.
Higher the thickness of the wire, greater is the current - carrying capacity of the wire. More number of insulation coats on the wire allows greater dielectric strength i.e, high voltage withstand capability which again depends on many other parameters like temperature, evenness in insulation coating etc.

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