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Transformer Testing & Measuring Instruments (Using PHCN as a Case Study)

Oyetola. J.B
Dept. of Electrical/Electronics Engineering,
School of Engineering,
Lagos State Polytechnic, Ikorodu, Lagos, Nigeria

Abstract

Power Holding Company of Nigeria (PHCN) has made use of transformers in various ways to supply electricity. But most of these transformers do pack-up after a period of time due to poor maintenance, lack of testing instruments, lack of protective devices, etc which lead to various faults in transformers. Most of these problems have been solved in generation and transmission levels, but much is yet to be done in the distribution level since most of the consumers know little about electricity. Overloading of transformers, accident on poles & lines, back feeding of lines, bad connections etc result in possible transformer failures. Tests and maintenance are performed to put a transformer back in operation but it requires much period of time that will put the affected consumers off. PHCN needs to replace the faulty transformer in order to give continuous supply pending the repair of the faulty one.

Keywords: Transformer, Fault, Short-circuit, Instruments

"1. Introduction"

In Nigeria, transformers are used by PHCN at different levels of Generation, Transmission and Distribution of power at a frequency of 50Hz. They could either be step-up or step-down transformers depending on the function they are meant to perform.

The transformer is an electro-magnetically coupled circuit which transforms power at different voltage and current levels. It is a vital link in a power system. It has made possible the power generated at lower voltage of about 16kV to be transmitted over a long distance at higher voltages such as 330kV and 132kV, at a frequency of 50Hz.

In this research, different faults that occur in transformers are analysed. In addition, all the accompanying measuring instruments used to carry out the tests are also discussed.

"2. Transformer Faults" [3]

Generally, fault in a system is the abnormal functioning of the system. Transformer faults on the other hand are the discontinuity or open-circuiting in transformers to perform its desired function.

Transformer faults can be divided into two main categories namely: -

(i) External or through faults
(ii) Internal faults

2.1 External or Through Faults

These are faults that occur outside the transformer but the effect is on the transformer to cause abnormality in it.

Transformers must be isolated from these faults as these faults produce electro-magnetically and thermal stresses in the windings which may ultimately lead to the failure of the transformer. Hence these faults must be cleared on time or after a pre-determined time. These faults are: -

(a) Overloads

A transformer can withstand overloads for certain period of time which depends on the rise of oil and windings temperature and the type of cooling used. Normally a 10% overload is permissible for not more than an hour, a 25% overload for not more than 15 to 20 minutes. Excessive overloading for long frequent and intermittent period results in rapid deterioration of the insulation and subsequently by failure. An overload condition with permissible overloads can be detected by a thermal relay or a temperature relay initially to give an alarm and finally to trip the transformer. When an alarm is sounded the operator must ensure to relieve the transformer from overload by pulling out non-essential loads i.e. load shedding. Normally, windings and oil temperature indicators are provided with alarm and trip contact on all power transformers.

(b) External Short-Circuit

An external short-circuit subjects the transformer to sudden electromagnetic stresses and overheating. Modern power

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transformers are designed to withstand short-circuit current of a certain kVA value for 1 second. The external short-circuit must be cleared within this period. An external short-circuit is detected primarily by the main protection of the loads or feeders and subsequently by the back-up protection of the transformer. As such these faults are detected by time graded over current relays.

(c) Terminal Faults

A terminal fault on the primary side of the transformer has no adverse effect. But a similar fault on the secondary side does have a serious effect. Such fault falls within the purview of the protected zone of the transformer and is detected by protective schemes to be covered under internal faults.

(d) Over-Voltages and Overfluxing

There are two types of over voltages to which a transformer is subjected. These are: (i) Sustained over voltages at power frequency (ii) Transient over voltages

"2.2 Sustained Over voltages"

Power frequency over voltages cause considerable damage to a transformer if allowed to persist because of the increased hysteresis and eddy current losses produced by the increased flux which flows through the structural parts of the transformer from the core area. Although the structural parts carry a very small amount of flux under normal conditions yet when they are subjected to this large leakage flux, rapid overheating takes place. This leads to deterioration of the insulation between the steel structure parts and the active part over voltages stress.

It can also be seen from the fundamental equation that the flux produced is proportional to the voltage, i.e.

$$\phi \; \alpha \; \frac{v}{f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$$

This relationship indicates that overfluxing can also arise from under-frequency and not necessarily due to over voltages. Under-frequency problems are encountered in large interconnected power systems during system instability. The relationship between flux, voltage and frequency has helped for the design of relay against overfluxing. This overfluxing relay constantly monitors the relationship v/f. The relay is of the two-step type similar to the two-step voltage relay. A safe value for v/f is taken as eqn(1) where v and f are expressed in per unit of the rated values. The modern practice is to install this overfluxing relay of the two-step type instead of over voltage relays. This is to take care of not only system over voltages by also system underfrequency.

Transient Over voltages

Transient over voltages are impressed on transformers connected to long overhead lines leading to interturn short-circuit of the transformer winding. Sometimes these transient over voltages may be due to lightning or switching. Protection against such transient over voltages is basically provided by: - (i) Spark gaps or rod gaps on the transformer bushings and (ii) By lightning arresters and surge diverters located close to the transformer.

The voltage rating of the surge diverter and the rod gap spacing is co-ordinated with the Basic Impulse Level (BIL) of the transformer. The rule of thumb for the location of the surge diverter is that it should be located at a distance being measured from the transformer winding along the circuit path to the surge diverter.

Some of the instruments used to protect the above faults are:

(1) Lightning arrester: - as stated above, is used to guide against over voltages such as thunder. The lightning arrester is expected to absorb the voltage produced by the thunder and ground it to earth.
(2) Horn gaps or spark gaps or rod gaps and surge diverters also perform the same function as the lightning arrester.
(3) Relays and circuit breakers: - a relay or electrical relay is a device designed to produce solid pre-determined changes in one or more electrical circuit after the appearance of certain conditions in the electrical circuit or circuit controlling it. It works with the circuit breaker to detect, locate and initiate the removal of the fault from the power system. The relay in power system usually trip off on over current and earth faults. The circuit breaker and relay are of different types, they should be able to discriminate and to change over the circuit breaker state from close to open or vice versa. In close position, sufficient pressure must hold the contacts together, overcoming all mechanical and electromagnetic forces caused by current flow
(4) Johnson and Philip (J&P) "D" fuse: - This is a fuse in form of D-shape installed between the feeder and the in-going cable into the transformer which cuts-off if a fault occurs on the line rather than damaging the transformer. The relay will then trip off on either over current or earth fault at the sub-station.
(5) Fuses at the feeder pillar also serves as protection against the damaging of the transformer in that the fuses are rated to a particular current which cuts-off if a fault occurs on the secondary side of the transformer.
(6) Reactors are installed at the tap changer to guide against any surges or over voltages going into the transformer.

2.2 Internal Faults

These are classified into two main categories: -

(i) Electrical Faults
(ii) Incipient or Miscellaneous faults

(i) Electrical Faults

These cause serious damage to the transformer and are detected by unbalanced current and voltage. These faults are: -

(a) Phase-to-earth fault on the primary/secondary terminals. This may arise when there is a short circuit between the phase and the earth where the current which is expected to produce flux flows to the ground. This may lead to burning of windings and thereafter causing high temperature.
(b) The windings are the essential part of the transformer which need to be well vanished, laminated to reduce eddy current and hysteresis of the transformer, any fault on it would lead to the damage of the transformer.
(c) Phase-to-phase faults on the high voltage (H.V) and /or low voltage (LV) windings or terminals inside the transformer would produce a surge which will destroy the windings.
(d) Short-circuit between turn of H.V and /or L.V winding also leads to transformer faults.
(e) Interturn faults in H.V windings:- Faults between phases and to earth inside a transformer are generally rare but most of the transformer failures are due to interturn faults. These faults being serious have to be isolate instantaneously.
(f) Terminal fault on the secondary:- These are faults involving bushing cracking or breaking, low contact, leakages.

(ii) Miscellaneous or Incipient Faults

These are actually faults of a minor nature, but if not taken care of may gradually, sooner or later develop into a major fault. Such faults are due to:

1. Poor quality or inadequacy of the insulation of the lamination and core bolt, which means that if the insulation used for the lamination is of poor quality, it would not last and may lead to leakages of flux thereby not giving the required outputs and might lead to high temperature.
2. Accidental damage to lamination and core bolt during erection and /or assembly. Since the lamination and core bolts are expected to be intact, any damage on it would lead to (i) above.
3. Poor quality or inadequacy of the insulation between windings, of the winding conductor and between windings and the core.
4. Low oil level:- Since the oil is expected to cool the transformer, heat produce under low oil level would lead to over heating of the transformer which would lead to rise in temperature.
5. Improper or not well grounded transformer and/or absence of protective devices would lead to transformer fault since the surges produce by external faults like thunder would not be grounded.
6. Deterioration of the insulation due to overload or ageing i.e. this will lead to interfluxing, losses like eddy current and hysteresis loss.
7. Deterioration of oil due to ingress of moisture decomposition caused by overloading or puncture, oxidation of the oil due to overheating, sludge formation which will make insulation oil less strengthened and low dielectric strength.
8. Coolant failure causing rise of temperature even when operating below full load conditions, checking of radiator tubes, fins due to sludge. Since high temperature oil goes up into the radiator of the transformer for cooling, if this is absent, it will lead to rise in temperature.
9. Mechanical damage to the windings due to bad handling during erection/assembly.
10. Badly formed joints or connection:- Though there is no moving part in transformer but when it is ON, it vibrates. So if the bolts are not well joined, there may result sludge formation with the oil due to cracking, arcing and low contacts.
11. Improper load sharing causing overheating due to circulating current i.e. current imbalance would lead to fault in transformer, since one winding would be more loaded than the other and may result in burning of windings or bursting of windings.

For the internal faults, there are some relays which are expected to take action when any of the above faults occurs, these are: -

1. Winding temperature relay which would trip off when the winding temperature is above the attainable one.
2. Oil temperature relay which would trip if the oil temperature rises above normal one.
3. Buchholz relay placed between the conservator and the tank to give alarm when the oil is getting low.
4. Sudden pressure relay
5. Over current and earth relay.

The instruments employed are: [4]

i. Pressure tester
ii. Avometer
iii. Oil tester
iv. Megger
v. Ratiometer

"3. Transformer Testing Procedures"[1]

Various tests are used to test the transformer after the fault occurrence. Faults could be confirmed after the tests have been carried out. These tests are performed in different categories to determine the actual fault.
The tests carried on transformer are as follows:

(a) Transformer Oil Test
Transformer oil is tested for dielectric strength and dielectric loss.

The dielectric strength test is carried out in a breakdown tester. To begin with, a sample of oil is drawn from the bottom or a special cock on the transformer tank into a clean and dry vessel at least 0.5 litre in capacity. The sample is then poured into a standard breakdown discharge chamber which is porcelain vessel fitted with two flat electrodes and brass current conveying rods connected to the set-up testing transformer.

Prior to a breakdown test, the oil sample is to stay for 20mins so that any entrapped air may escape. Then the voltage applied to the electrodes is raised gradually until a breakdown take place, and the kilovoltmeter is read for the value of voltage at which this happens. A total of six breakdowns are caused to occur at 5mins intervals. The reading taken after the first breakdown is discarded, and the breakdown voltage is taken as the arithmetic mean of the remaining five indications. For transformers up to 15kV in size, it should be 25kV, and for transformers in size above 15kV to 35kV, it should be 30kV.

The oil used to fill reconditioned transformers is also subjected to an abridge chemical analysis in order to determine its acid number, the flash point of its vapour, the reaction of a water extraction, the suspended carbon content, and the mechanical impurity content.

(b) The Ratio and Phase Interconnected Test

The type of circuit used for measuring the transformer ratio of a reconditioned transformer is also used to check phase interconnections and connection of taps to tap changer.

The test is carried out by applying a voltage (which at least 2% of the rated value) simultaneously to all the phases of the transformer and in each step of voltage adjustment by the tap changer. The variation in voltage between the phases should not exceed 2%.

The phase interconnections are checked to make sure that the windings have been interconnected correctly and that the angular (phase) displacement is as it should be.

(c) The D.C (Injection) Winding Resistance Test

This test is applied to every reconditioned transformer in order to bring out any likely defects passed unnoticed during repair, such as broken parallel conductors, poor soldered (brazed) joints at the tap changer, and the likes. These defects raise the d.c resistance owing to an increase in the contact resistance at the joints and within the defective sections. The variations in resistance between the phases and the various steps of voltage control should not exceed 2%.

(d) The Open-Circuit and Short-Circuit Current and Loss Tests

The open-circuit test (also known as the core loss and magnetizing current test) is carried out in order to detect defects in the core of the transformer which may lead to an increase in the open-circuit (magnetizing) current and the associated losses, so that the overall efficiency of the transformer is reduced or the transformer is overheated.

The procedure for an open-circuit test is as follows: - the L.V winding is energised with a balanced 50Hz voltage, with the H.V winding open-circuited, and the applied voltage is gradually raised from zero to the rated value. In the process, the wattmeter connected in the test circuit is read for the power drawn by the transformer, and the ammeter is read for the line-to-line current. As an alternative, an open-circuit test may be carried out at a reduced voltage, but the result must then be transformed to the rated values by calculation.

When the repair of a transformer involves the replacement of a winding or windings, it may sometimes happen that the conductors has been transposed incorrectly, or one of the parallel conductor has been partly or fully broken, or soldered joints have been made improperly, or the conductor have cross-sectional smaller than it should be. All of these defects raise the Ohmic resistance of the windings and entail an additional loss under load. The defects can be detected by a short-circuit test and by comparing the results thus obtain with the design (or calculated) values.

The procedure for a short-circuit test(which is also known as load loss and impedance test) is as follows: - the terminals of the L.V windings are short-circuited with pieces of strip conductor, and the H.V winding is energized with a voltage that will cause the rated full-load current to flow in the windings (that is, the impedance voltage). The measured input power represents the total load loss at rated load on the complete transformer.

In reference table, the load loss is quoted for a temperature of 75^0c. So, in carrying out a short-circuit test, it is important to measure the actual temperature of the windings and to re-scale the results accordingly. The load loss found by the test is compared with the design value. If the actual value is greater than the design one, the transformer has some defects.

(e) The Insulation Resistance Test

The insulation resistance from the H.V winding to the tank with the L.V winding grounded from the L.V winding to the tank with the H.V winding grounded and between the L.V and

H.V windings connected together and to the tank is measured with a Megohmeter. For transformer in sizes up to 35kV, the insulation resistance as measured at 20^0c is taken to be satisfactory if it is not less than 300MΩ for transformers in sizes up to 6.3MVA inclusive, and 600MΩ for transformers in sizes 10MVA and higher.

(f) The Applied High Tension, Power-Frequency (50Hz) Test of the Major Insulation for Dielectric Strength

An applied high-tension test is normally made, in turn, between each winding and the core, and all other winding connected to earth.

The test consists in that the voltage taken from an external a.c source is applied via a testing transformer to the winding under test. This is done by connecting one of the leads of the testing transformer to the terminals of the winding under test joined together, and the other lead to the grounded tank. The leads of the other windings of the transformer under test are connected together and to the ground frame. The applied voltage is raised gradually from zero to the test value with the aid of an adjusting transformer connected to a 50Hz source. If the ammeter does not indicate an increase in current and the voltmeter does not indicate a reduction in voltage, and no discharge (cracking noise) is observed inside the transformer for one minute after the test voltage is applied, the voltage is gradually reduced to zero and it is assumed that the transformer has passed the test. The above procedure is first applied to the L.V winding, then to H.V windings.

For oil-immersed transformer, the major insulation test voltage is 25kV for transformers in sizes up to 6kV, 35kV for transformers in sizes up to 10kV, and 85kV for transformers in sizes up to 35kV.

(g) The Induced High-Voltage Test of the Turn Insulation

This test involves exciting the transformer on open-circuit at a voltage higher than normal for a short period. The purpose of the induced high-voltage test is to prove the strength of the insulation between turns and between other parts of the transformer operation at different potentials. The test voltage is 115% of the rated value for bolted cores, and 130% of the rated value for boltless (or banded) cores. The transformer is taken to have passed the test, if no current inrushes, discharges and other symptoms of defects are observed during 1min of the test period.

The post-repair tests also include testing the transformer tank for tightness. On transformer equipped with on-load tap changers, it is also necessary to test the entire voltage-adjustment arrangement (including the operating mechanism and the control cabinet). If the operating mechanism is controlled by means of relays, these, too, must be tested for proper operation.

"4. Transformer Fault Analysis" [2]

Connections Used

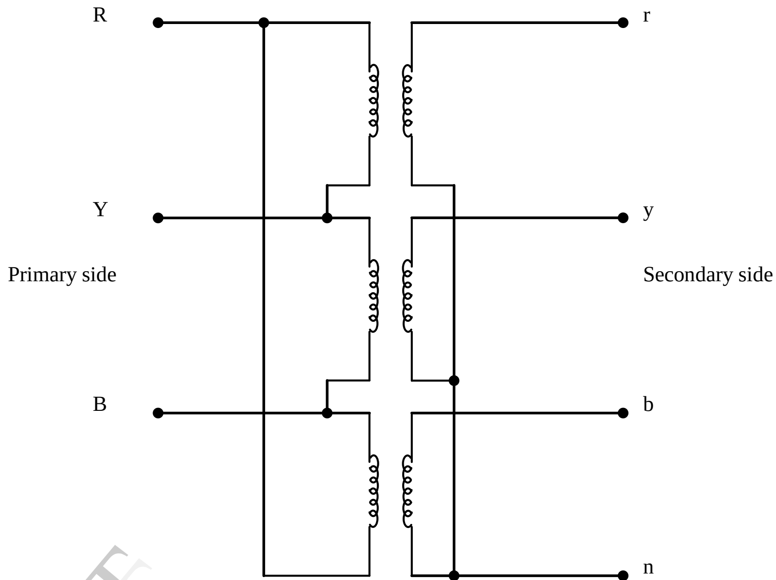

Fig 1: Vector Group DynII

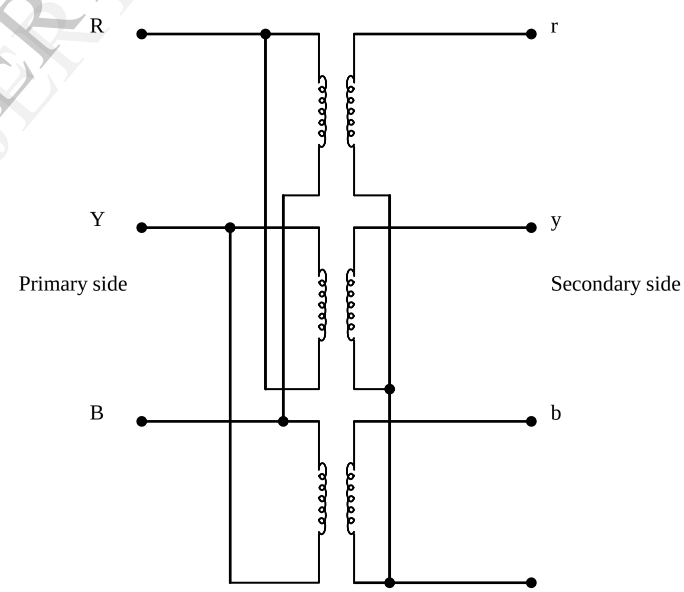

Fig 2: Vector Group DynI

Analysis I

MAKE	:	Enertech LTD (FRANCE)
RATING	:	500kVA, 11/0.415kV
VECTOR GROUP	:	Dyn I
PHASE	:	3
FREQUENCY	:	50Hz
S/No	:	539955

"Table1: Insulation Test on Transformer"

Side Under Test	Phase	Continuity	Injected Voltage	Leakage Current	Period (mins)	Remark
H.V	R	O.K	25kV	Trace	4	O.K
Side	Y	O.K	25kV	Trace	4	O.K
xf	B	O.K	25kV	Trace	4	O.K
L.V	R	O.K	25kV	Trace	1	O.K
Side	Y	O.K	25kV	Trace	1	O.K
xf	B	O.K	25kV	Trace	1	O.K

"Table 2: Insulation Test on Cable: Cross Link Polyethylene Insulated (XLPE) Type"

Phase	Injected Voltage	Leakage Current	Period (mins)	Remark
R	25kV	2μA	3	O.K
Y	25kV	2μA	3	O.K
B	25kV	2μA	3	O.K

"Table 3: Ratio Test: Using Single-Phase Supply Sec. Side Voltage"

Tap Position	Primary Voltage	R-Y	Y-B	R-B	R-N	Y-N	B-N	Remark
3	220V	9.2	4.4	4.4	4.4	4.4	0.0	O.K
3	220V	4.4	9.2	4.4	0.0	4.4	4.4	O.K
3	220V	4.4	4.4	9.2	4.4	0.0	4.4	O.K

"Table 4: Oil Dielectric Strength Test"

Spacing (mm)	Breakdown Voltage	Period (mins)	Remark
2.5	40kV	5	Discarded
2.5	42kV	5	
2.5	39kV	5	
2.5	40kV	5	
2.5	38kV	5	
2.5	41kV	5	
	Average: 40kV		O.K

Substation Earthing

i. Lightning Arrester 9Ω
ii. Transformer Body 9Ω
iii Feeder Pillar 9Ω

"Table 5: Step-Up Test (Excitation Current)"

Phase	Current
R	2.4A
Y	2.0A
B	2.2A

The test above proved okay but the substation requires more as 2Ω is the standard resistance value.

Analysis II

MAKE	:	Mitsubishi
RATING	:	500kVA, 11/0.415kV
VECTOR GROUP	:	Dyn II
PHASE	:	3
FREQUENCY	:	50Hz
S/No	:	L511010521

"Table 6: Insulation Test on Transformer"

Side Under Test	Phase	Continuity	Injected Voltage	Leakage Current	Period (mins)	Remark
H.V	R	O.K	25kV	Trace	2	O.K
Side	Y	O.K	25kV	Trace	2	O.K
xf	B	O.K	25kV	Trace	2	O.K
L.V	R	O.K	2kV	1μA	2	O.K
Side	Y	O.K	2kV	1μA	2	O.K
xf	B	O.K	2kV	1μA	2	O.K

"Table 7: Insulation Test on Cable: Cross Link Polyethylene Insulated (XLPE) Type"

Phase	Injected Voltage	Leakage Current	Period (mins)	Remark
R	Soaked with water			Bad
Y	20kV			Bad
B				Bad

"Table 8: Ratio Test: Using Single-Phase Supply Sec. Side Voltage"

Tap Position	Primary Voltage	R-Y	Y-B	R-B	R-N	Y-N	B-N	Remark
3	219V	4.8	4.8	9.7	4.8	0.0	4.8	Bad
3	219V	0.0	4.8	4.8	0.0	0.0	4.8	Bad
3	219V	4.8	0.0	4.8	4.8	0.0	0.0	Bad

"Table 9: Oil Dielectric Strength Test"

Spacing (mm)	Breakdown Voltage	Period (mins)	Remark
2.5	18kV	5	Discarded
2.5	16kV	5	
2.5	19kV	5	
2.5	15kV	5	
2.5	17kV	5	
2.5	19kV	5	
	Average: 17.2kV		Bad

The ratio test, insulation test on cable and transfer oil dielectric strength test all failed. The standard breakdown voltage for 11/0.415kV at 2.5mm gap spacing of oil strength is 25kV and above.

Substation Earthing

i. Lightning Arrester 3.4Ω
ii. Transformer Body 12Ω
iii Feeder Pillar 2.5Ω
NB: Transformer earthing to be connected back. LT cable to be reconnected and HT (XLPE) cable to be warmed

"5. Recommendation and Conclusion"

To minimize faults in transformers, PHCN needs to computerize its network, employ skilful technicians to handle the transformers, expand their workshop since Ijora is the only workshop nation-wide and then improve on the equipments. All tests should be carried out if there is a fault and it should be handled by the protection officials.

The pubic needs to be enlightened on transformer since most faults are caused by them. Through by which accident, overloading, non-planning of networks i.e. they need to inform PHCN before building their houses for proper networks and good connections.

Since most of the transformer faults do occur at the distribution level, it is therefore concluded that PHCN has tried a lot to supply us electricity but they need to improve on the distribution so as to "make life a little easier" for us all.

"6. References"

[1] H.A. CARR; The Testing of Transformer and Electrical Machines; Macdonalds & Co. (Publisher), 1961
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[3] PHCN, Workshop; Transformer Faults and Remedies, Ijora, 1984
[4] Manuals on Measuring Instruments; PHCN, 1980