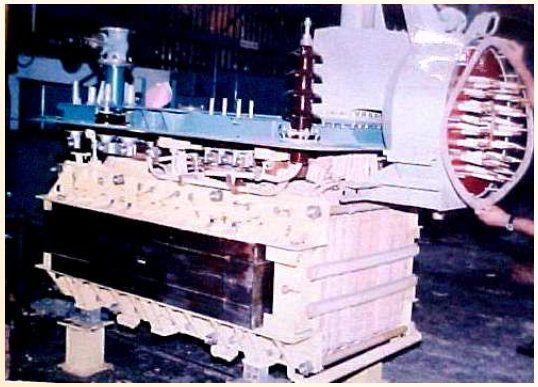
INTRODUCTION

The transformer is a static device, which transforms power from one AC circuit to another AC circuit at same frequency but having different characteristics. These circuits are conductively disjointed but magnetically coupled by a common time varying magnetic field. It can raise or lower the voltage with a corresponding decrease or increase in current.

In conventional electric locomotives, speed control is achieved by limiting the value of current and supply of variable voltage to the traction motors with tap changer during starting. However in case of 3 phase locomotives output of the transformer is connected to the solid state converters and motors are operated on variable voltage variable frequency (VVVF) principle.

DIFFERENT PARTS & COMPONENTS OF TRANSFORMER

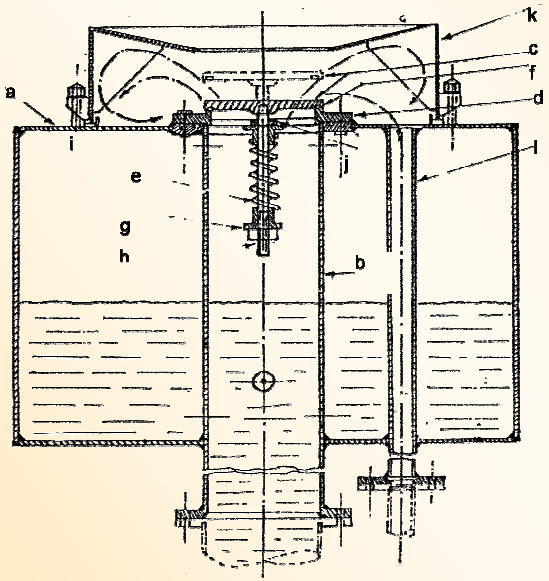


Core and winding	Transformer tank
Protection system fittings	LV bushings
HV bushings	Main bushing
Conservator	Breather
Tap changer with driving arrangement	Radiator
Oil circulating pump	Oil isolating cocks
Oil outlet valve	Oil level indicator

PROTECTION SYSTEM FITTINGS

The most common protection fittings are as follows:

1. Oil and airflow relays in cooling circuit ensures oil flow and cooling of transformer.
2. CT in primary circuit ensures protection against excessive overload and short circuits.
3. Arcing horn ET2 placed on the roof of the locomotive protect primary side from voltage surges.
4. Surge condensers to protect auxiliary winding.
5. Breather with Silica gel prevents the ingress of moisture.
6. Safety valve fitted in the oil conservator guards oil tank against over pressure (explosion).



a – Conservator	b - Guide tube	c – Cover	d – Flange
e - Pressing spring	f – Gasket	g – Nut	h - Split pin
i - Gliding bush	k - Overflow chamber		l - Discharge pipe

The transformer is also fitted with the following accessories:

1. Oil level indicator marked with temperature level in deg.C.
2. HV and LV bushings with terminals.
3. Oil flow indication relay (QPH).
4. Air flow indication relay (QVRH).
5. Connection diagram plate and a plate indicating the lifting of the active part of the transformer.

WORKING OF IMPORTANT COMPONENTS

- **Conservator**

  Maintains the oil level in tank
  Provides space for the expansion of oil.

- **Oil level Indicator**

  It indicates level of insulating oil in the transformer tank. It has markings on transparent sheet for maximum & minimum levels in deg C.

- **Breather**

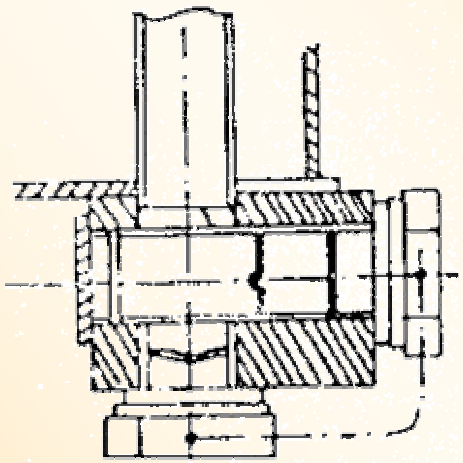
  It is attached to conservator tank and contains silica gel, which prevents the moist air from entering into the tank during contraction of oil and provides gas passes to atmosphere during expansion.

- **Outlet Valve**

  It provides passage to drain the oil during overhauling or as and when required oil sample for testing.

- **Inlet Valve**

  It provides passage to pour the transformer oil in the tank during purification or in case of shortage found in the tank.



FACTORS AFFECTING LIFE OF TRANSFORMER

Life of transformer is affected by the following factors:

- **Effect of Moisture**

  Presence of moisture in oil adversely affects the dielectric properties of oil and solid insulation of transformer. As paper insulation is highly hygroscopic in nature, it absorbs the moisture from oil and reduces its life. Solubility of moisture in oil increases with increase in temperature and oxidation products of oil. When the oil in service oxidizes, acids are formed. These acids increase moisture solubility of oil. Acids coupled with moisture further decompose the oil forming more acids and moisture. Thus the rate of deterioration of oil increases.

- **Effect of Oxygen**

  The oxygen reacts and decomposes the cellulose of insulation. This forms an organic acid soluble in oil and sludge, which blocks the free circulation of the oil. The adverse effect of oxygen, which may be aggravated by catalytic action between hot oil and bare copper, increase the operating temperature.

- **Effect of Solid Impurities**

  The solid impurity present in the oil reduces its dielectric strength considerably. A good remedy is to filter the oil periodically.

- **Effect of Varnishes**

  Some varnishes having oxidizing effect, react with transformer oil and precipitate sludge on windings. Synthetic varnishes having acid inhibiting properties, generally delay the natural formation of acid and sludge in the oil.

- **Effect of Slackness of winding**

  After few months of service, the transformer coils may suffer natural setting. This may wear the conductor insulation at some places and lead to an inter-turn failure. The coils may also get displaced under load conditions or momentary short circuit conditions, which may result in electrical and magnetic unbalance and produce even greater displacement. A good practice is, therefore to lift the core and windings to take up any slackness present at the first IOH after commissioning.

TECHNICAL DATA OF DIFFERENT TYPES OF ELECTRIC LOCO TRANSFORMERS

Common Technical Ratings for 3900kVA (WAM4, WAG5, WAP1) & 5400 kVA (WAG5HB, WAG7, WAP4) transformers

Rated voltage	Normal : 25.0 kV	Maximum : 27.5 kV	Minimum : 19.0 kV
Short time	Minimum : 17.5 kV	Maximum : 30 kV for short duration	
Minimum primary voltage for guaranteed traction	22.5 kV		
Minimum voltage for functioning of auxiliaries	17.5 kV		
Frequency	50 Hz ± 1.5 Hz		
Cooling	Oil forced, air forced cooled (OFAF)		
% Impedance voltage at 32 tap	10% ± tolerance as per IEC 310		
No. of traction winding	Two		
Insulation	Class ‘A’ (105 deg C) with mineral oil		
Emergency operation	In the event of failure of cooling system i.e. oil circulating pump and radiator blower, the transformer shall be able to deliver 50% of the traction current for half hour after having worked at 90% of the full load before failure.		
Percentage overload rating after running continuously at 90% full load.	60% for two minutes followed by 50% for 10 minutes.		

Difference in ratings for 3900kVA (WAM4, WAG5, WAP1) & 5400 kVA (WAG5HB, WAG7, WAP4) transformers

	3900 kVA Transformer	**5400 kVA Transformer**
Rated secondary no load voltage at 32 tap under catenary voltage 22.5 kV	865 V	Approx. 1000 V
Total continuous rated current of secondary	4500 A (2 x 2250A)	5400 A (2 x 2700A)
Primary input	4170 kVA	5670 kVA
Total apparent power of the secondary at 22.5 kV	3900 kVA	5400 kVA
System of connection of traction windings	Two independent windings but capable of being connected in series/ parallel combination.	One winding for each rectifier bridge
Total weight	11730 kg.	12200 kg.

Auxiliary winding ratings for 3900kVA (WAM4, WAG5, WAP1) & 5400 kVA (WAG5HB, WAG7, WAP4) transformers		
	ARNO	Static converter
Approximate no load voltage under 22.5 kV catenary voltage	415V	830 V
Continuous rated apparent power for auxiliary winding	270 kVA	270 kVA
Percentage impedance drop	3-5%	3-5%

Transformers for 25kV AC electric locomotive class WAG9, WAP5, WAP7

Common Ratings for WAG9, WAP5 & WAP7 Loco Transformers

Rated voltage	
Normal Maximum Minimum	25.0 kV 30.0 kV 17.5 kV
Frequency	50Hz ± 6 %
Cooling medium	Inhibited transformer oil to IEC–296/ IS-12463
Series Resonant Choke (2SOD 240)	
Inductance	0.551 mH (± 15 %), Liner to I_{peak} = 1391A
Thermal current I_{th}	984A
Resonant frequency	100Hz
Voltage stress between terminals to earth	Nominal 482 Vac , Max. 3471 V
Auxiliary Converter Choke (6GOD 120)	
Inductance per PUR - choke	
0A	30 mH
120A	30 mH
155A	26 mH
190A	20 mH
Frequency	100 Hz
Current	Rated 155A, Max. 190A
Ripple	Nominal 38.6%, Max. 50.2%
Voltage to earth	Rated 1153 V, Max. 2000 V

Ratings for WAG9 loco transformer

Winding	Power (kVA)	Voltage (V)	Current (A)
HV	6531	25000	261.25
Traction	4 x 1449	4x 1269	4 x 1142
Auxiliary (BUR)	334	1000	334
Filter	400	1154	347
Total weight	9450 ± 3 % kg		

Ratings for WAP5 and WAP7 Loco Transformer

Winding	Power (kVA)	Voltage (V)	Current (A)
HV	7475	25000	299
Traction	4 x 1449	4 x 1269	4 x 1142
Auxiliary (BUR)	334	1000	334
Filter	400	1154	347
Hotel load	945	750	1260
Total weight	10000 ± 3 % kg		

TESTS ON TRANSFORMER

Following common tests may be carried out in the transformer either in case of failure or during overhauling:

➢ Meggering

Check the insulation resistance with 1 kV megger between end frame and core, end frame and steel ring. It should be more than 5 M ohms.

Check the insulation resistance of different windings to earth with 2.5 kV megger. It should be more than 100 M ohms. If this is less, dry out the transformer.

➢ Continuity Test

Check the continuity of the following windings with the multimeter:

- Primary winding across A0 – A33
- Secondary windings across a3 –a4, a5 – a6
- Auxiliary winding across a0 – a1

➢ Winding Resistance Test

Sn	Winding	Resistance value	
		HETT 3900	HETT 5400
1	A0 – A33	0.843 – 1.243	0.698 – 1.116
2	A0 – A34	0.430 – 0.598	0.241 – 0.320
3	a3 – a4	0.0015- 0.0025	0.0015- 0.0025
4	a5 – a6	0.0015- 0.0025	0.0015- 0.0025
5	a0 – a1	0.0025- 0.004	0.0025- 0.004

➢ Ratio Test

Apply 230V a.c. supply to the primary winding of the transformer across A0 – A33 and keep tap changer at 32 notch and check the voltage appearing at the following terminals.

	For HETT 3900	For HETT 5400
a. Voltage across a-0 – a-1 (Calculated)	3.98 Volts	3.98 Volts
b. Voltage across a3 – a4 & a5 – a6	8.90 Volts.	9.60 Volts

c. At all notches as under:

Notch	HETT 3900	HETT 5400	Notch	HETT 3900	HETT 5400	Notch	HETT 3900	HETT 5400	Notch	HETT 3900	HETT 5400
1	0.25	0.28	9	2.1	2.28	17	4.32	4.75	25	6.75	7.50
2	0.53	0.58	10	2.37	2.60	18	4.60	5.10	26	7.18	7.75
3	0.81	0.88	11	2.65	2.80	19	4.85	5.45	27	7.45	8.20
4	1.08	1.25	12	2.93	3.20	20	5.15	5.65	28	7.68	8.45
5	1.27	1.38	13	3.20	3.50	21	5.42	5.95	29	7.80	8.75
6	1.46	1.60	14	3.47	3.75	22	5.71	6.25	30	8.25	9.10
7	1.63	1.78	15	3.74	4.15	23	6.05	6.65	31	8.55	9.30
8	1.81	2.00	16	4.02	4.45	24	6.45	7.10	32	8.90	9.60

➢ Oil Testing

As per RDSO SMI No.RDSO/ELRS/SMI/158 dtd. 19.01.95, following tests to be carried out on the transformer oil in service.

Draw a sample of the oil from the transformer as per method given in IS: 6855-1973 or IS: 9434-1979depending upon the characteristics to be evaluated. The quantity of oil drawn should be 4 litres instead of 2 litres prescribed in these standards.

Sr. No.	Tests	Test methods	Periodicity	Permissible limits	Requirement of new filtered oil
1.	Visual inspection	As per IS 12463-1988	IC/AOH/IOH/POH	---	The oil shall be clear & transparent and free from suspended matter or sediments.
2.	Dissolved gas analysis	SMI-138	IC/AOH/IOH/POH	As per SMI-138	---
3.	Electrical strength (break down voltage)	IS:6792-72	IC/AOH/IOH/POH	30 kV (rms) (min.)	60 kV (rms)
4.	Water content (PPM)	IS:335-1983	IC/AOH/IOH/POH	35 PPM (Max.)	25 PPM (Max.)
5.	Specific resistance at 90 degree C (Ohm-cm)	IS: 6103-71	IC/AOH/IOH/POH	0.1 x 10^{12} ohm-cm (Min.)	35 x 10^{12} ohm-cm (Min.)
6.	Dielectric dissipation factor (Tan Delta) at 90 degree C.	IS: 6262-71	AOH/IOH/POH	1.0 (Max.)	0.002 (Max.)
7.	Total acidity	IS:1448-67	IC/AOH/IOH/POH	0.5 mg KOH/gm. (Max.)	0.08 mg.KOH/ gm.
8.	Sediments and perceptible sludge	IS:1866-83 Appendix-A	AOH/IOH/POH	0.05 % by wt.	No sediment or perceptible sludge shall be detected.
9.	Flash point	IS: 1448-1970	IOH/POH	125 deg. C (Min.)	140 deg. C (Min.)
10	Interfacial tension at 27 degree C	IS: 6104-71	IOH/POH	0.018 N/m (Min.)	0.04 N/m (Min.)
11	Oxidation Inhibitor	IS: 335-1983 Appendix 'D'	AOH/IOH/POH	0.3 % by mass (Max.)	0.3 % by mass (Max.)

- Compare the results with the earlier results recorded on the same oil. **Any abrupt change** in the value of the parameters is indicative of the unhealthiness of the transformer. The transformer should be opened for detailed internal inspection for any incipient fault. However, if the flash point falls by 15 degree C from its initial value, replace the oil with new filtered oil without opening the transformer.

- If the colour of the oil has became dark brown, which is indicative of presence of dissolved copper, change the oil with new filtered oil meeting characteristics given in Annexure I of SMI 158.
- For interpretation of results of dissolved gas analysis, follow the instructions given in RDSO SMI No. 138.
- If either of the parameters i.e. flash point, interfacial tension, specific resistance, total acidity and dielectric dissipation factor are beyond the permissible limits, replace the oil with new filtered oil.
- If inhibited, measure and record the inhibitor content in the oil.

CONDITION MONITORING OF TRANSFORMER BY DISSOLVED GAS ANALYSIS (DGA)

In order to detect incipient faults in the transformer and to arrest deterioration/ damage to the transformer insulation, gases dissolved in the transformer oil are detected, analysed and preventive measures adopted.

Gas Chromatography method is used for detection of the dissolved gases and identification of incipient faults. The most significant gases generated by decomposition of oil and deterioration of paper insulation on the conductor are hydrogen, methane, ethane, ethylene and acetylene. The quantities of these gases dissolved in transformer oil vary depending upon the type and severity of the fault conditions.

➢ Sensitivity Limits

Gas Chromatography apparatus should be able to detect the following minimum concentration of dissolved gases:

Hydrogen	:	05 ppm
Hydrocarbon	:	01 ppm
Carbon oxides	:	25 ppm

➢ Establishment of Norms

The contents of various dissolved gases in the transformer oil vary with design and operating conditions. It is desirable that the values of concentration of gases of healthy transformers of different age groups are to be gathered by the Railways concerned to evolve suitable norms. However, as a starting point, the permissible concentrations of dissolved gases in the oil of a healthy transformer are given below as guidelines:

Gas	Less than 4 years in service (ppm)	4-10 years in service (ppm)	More than 10 years in service (ppm)
Hydrogen (H_2)	100/150	200/300	200/300
Methane (CH_4)	50/70	100/150	200/300
Acetylene ($C_2 H_2$)	20/30	30/50	100/150
Ethylene ($C_2 H_4$)	100/150	150/200	200/400
Ethane ($C_2 H_6$)	30/50	100/150	800/1000
Carbon dioxide (CO_2)	3000/3500	4000/5000	9000/10000

➢ Establishment of Reference Values/ Bench Marks

To establish a reference value/ bench mark, gases generated from **initial sample of oil** from each healthy transformer should be collected. Results of the analysis are taken as a reference value/ benchmark. Results of later periodic analysis are compared with the benchmark for each transformer.

➢ Diagnosis of Fault

Basic diagnosis of DGA is based upon the quantities of gases generated. Types of gases in excess norms produced by oil decomposition/ cellulosic material depends upon the hot spot temperature produced by faults.

Characteristics of gases associated with various faults are as under:0

Methane (CH_4)	Low temperature hot spot
Ethane ($C_2 H_6$)	High temperature hot spot
Ethylene ($C_2 H_4$)	Strong over heating
Acetylene ($C_2 H_2$)	Arcing
Hydrogen (H_2)	Partial discharge
Carbon dioxide (CO_2)	Thermal decomposition of paper insulation
Carbon monoxide (CO)	

➢ Word of Caution

To start with the diagnosis, it is necessary to be satisfied that measured gas concentrations are significant and high enough to warrant diagnosis, because some amount of gases will always be there due to normal operating conditions without any fault but it can be sufficient to be misleading. The reasons for the situation are:

- Gases formed during the refining processes and not completely removed by oil degassing.
- Gases formed during drying and impregnating the transformer in sheds/ workshops.
- Gases formed in the event of previous faults and not completely removed from the oil-impregnated insulation before being refilled with degassed oil.
- Gases formed during repairs by brazing, welding, etc.

➢ Procedure for Fault Diagnosis

- Obtain the results of concentration of various gases in terms of ppm.
- Compare the concentrations with sensitivity limits. These should be at most ten times the sensitivity.
- If it exceeds sensitivity limits, compare with benchmarks.
- If it exceeds benchmarks, compare concentrations with norms depending upon age and design of transformer.

DO'S

- Check the protection system of transformer periodically.
- Attend any type of oil leakage at the earliest possible.
- Ensure periodic testing of transformer oil.
- Maintain transformer wise record of parts of transformer and transformer oil for future reference.
- Maintain conservator oil level above 15 degree C mark.

DON'TS

- Don't use under capacity lifting jacks
- Don't leave any loose connection
- Don't over tight the nuts & bolts to stop any leakage Don't keep the breather pipe open or exposed
- Don't impinge hot oil jet on the transformer windings for cleaning.

Disclaimer:

It is clarified that this pamphlet does not supersede any existing provisions laid down by RDSO, Railway Board or Zonal Railways. The pamphlet is for guidance only and it is not a statutory document.

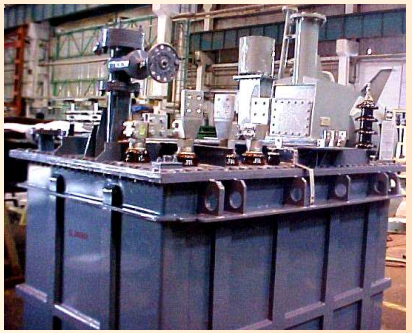
If you have any suggestion or comment, please write to:
Director (Electrical), CAMTECH, Maharajpur, Gwalior (M.P.) – 474 005
Ph.0751-2470740, Fax 0751-2470841
E-mail: direlcamtech@gmail.com

(For Official Use Only)

भारत सरकार **GOVERNMENT OF INDIA**
रेल मंत्रालय **MINISTRY OF RAILWAYS**

PAMPHLET
on
AC ELECTRIC LOCOMOTIVE TRANSFORMERS

CAMTECH/E/2011-12/LOCO-TFP/1.0
May 2011



अआमासं RDSO रेल अनुसंधान Transforming Railways

An ISO 9001-2000 Certified Organisation उच्चतम रखरखाव प्रौद्योगिकी केन्द्र

Excellence In Maintenance

Indian Railways
Centre for Advanced Maintenance Technology

महाराजपुर, ग्वालियर – 474 005
Maharajpur, GWALIOR - 474 005