Government of India
Ministry of Railways
Research, Designs & Standards Organisation
Manak Nagar, Lucknow - 226 011

No. EL/3.2.1/3 **Dated:** As signed.

SPECIAL MAINTENANCE INSTRUCTIONS NO RDSO/ELRS/SMI/138, Rev.1 CONDITION MONITORING OF TRACTION TRANSFORMERS BY DISSOLVED GAS ANALYSIS

1. OBJECT

1.1 Gases may be formed in oil filled electrical equipment due to ageing but also to large extent as a result of fault. The principal mechanism of gas formation includes oxidation, insulation-decomposition, oil breakdown and electrolytic action.

1.2 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.

1.3 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.

1.4 There are various ways of interpreting the gases found during DGA. Currently the interpretation of DGA results are carried out based on concentration of gases, IS-10593/IEC 60599 provides a method to interpret DGA result based on ratio of gases for power transformer. It enable precise pinpointing of fault. ELS/CNB based on their case study in loco no 32231/WAG-9HC, transformer having normal DGA result as per SMI-138 but as per ratio of gases interpretation, thermal fault (T2) has been identified and same has been noticed after dismantling of transformer that bushing was found damaged due to overheating i.e loose connection. ELS/CNB advised to add these interpretation methods given in IS-10593/IEC 60599 in SMI-138. Henceforth, same has been incorporated.

2. INSTRUCTIONS

The apparatus used for the dissolved gas analysis, its requirements, methodology of various steps involved in the analysis i.e. extraction, separation, identification and quantification of the gases, diagnosis of the fault based on concentration of the gases and basic gas ratio (C_2H_2/C_2H_4, CH_4/H_2, C_2H_4/C_2H_6), procedure for fault diagnosis and establishment of norms, together with sample calculations are enclosed in Annexure-I.

3. REFERENCE

The following documents specified may be referred to in this connection:-

- IS : 10593 -(2023)/IEC:60599 (2022)	:	Norms for gas analysis.
- IS : 9434 -(2019)/IEC:60567(2011)	:	Guide for sampling and analysis of free and dissolved gases in oil filled electrical equipment.

- INSTRUCTION DRAWING.

- Gas extraction system for guidance (Annexure – II)
- Typical arrangement of gas chromatograph (Fig.1.)
- Sample strip chart recording (Fig.2)

4. APPLICATION.

All Conventional & Three Phase AC Electric Locomotives and AC EMUs/MEMUs provided with mineral insulating oil.

5. AGENCY OF IMPLEMENTAION

Electric/Diesel Loco Sheds and EMU/MEMU Car Sheds.

6. PERIODICITY OF IMPLEMENTAION

As per CLW letter no. ELDD/3254/part dated 23.07.2021 for OEMs & during every IC, TOH, IOH & POH schedule for Zonal Railways.

7. DISTRIBUTION

As per Standard Mailing List.

Encl: Annexure-I, II, Fig. 1 and 2

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For Director General(Stds.) /Elect.

Annexure-I

1. APPARATUS

The following apparatus is required for the purpose of dissolved gas analysis:-

1.1 Three column gas chromatograph latest model available in the market as per IS:10593:2023 & 9434:2019.

1.2 Potentiometric strip chart recorder.

1.3 Gas extraction apparatus, vacuum pump and hot plate-cum-magnetic stirrer. The sketch showing the arrangement of the apparatus is given at Annexure-II.

1.4 Sensitivity: The gas chromatograph apparatus should be able to detect the following minimum concentration of dissolved gases:-

Hydrogen	: 5 ppm
Hydrocarbon	: 1 ppm
Carbon oxides	: 25 ppm

2. METHODOLOGY

2.1 Collection of representative oil sample

The sample shall be obtained with the use of syringes, bottles or sampling tube. The detailed method of sampling is described in IS: 9434:2019 & same should be followed. Following information should be obtained and records to be maintained for future reference.

a) Name of the Shed/Shop
b) Identification of the equipment
c) Date of sampling
d) Type of oil
e) Date of commissioning of transformer
f) Date of last filtration of oil
g) Details of repair carried out since the commissioning of the transformer
h) Date of last dissolved gas analysis
i) Object of sampling (whether investigation or routine)

2.2 Extraction of gases dissolved in oil.

Refer IS:9434:2019. Extract the dissolved gases from the oil sample by means of gas extraction apparatus. See sketch at Annexure II for guidance.

2.3 Separation, identification and quantitative determination of gases.

2.3.1 Calibrate the chromatograph by injecting the known amount of pure gases and establish the calibration curve and retention time. Inject the extracted gas sample to the gas chromatograph for separation and analysis. Gases to be determined are Hydrogen (H2), Methane (CH4), Ethane (C2H6), Ethylene (C2H4), Acetylene (C2H2), Carbon-dioxide(CO2). One typical arrangement is shown in Fig. 1.

2.3.2 For determination of above gases, various carrier gases and columns are used. The output of the columns is connected to Thermal Conductivity Detector (TCD) and Flame Ionisation Detector (FID). Gases to be detected, carrier gases, associated columns and means of identification are as under:-

Name of gases to be identified	Carrier gas	Column	Means ofidentification
Hydrocarbon	N_2	Silica gel	Flame ionisation detector (FID)
Air, CO_2	H_2	Porapak Q	Thermal conductivity tester (TCD-1)
H_2	N_2	Molecular sieve	Thermal Conductivity tester (TCD-2)

The signal generated by TCD and FID is mv vs time plot. Amplified signal of the detector is recorded on 2-potentiometric-chart recorder. The signals appear in the form of peaks as illustrated in Fig.2.

2.3.3 Calculation.

After recording of results of gas samples on a strip chart recorder, measure area of each gas peak. Identify the gases corresponding to each peak by comparison with chromatographs obtained by calibration. Gas volume in terms of micro litre per litre of oil shall be obtained by the following formula:-

Micro litre/ litre of any particular gas-

$$= \text{ppm of standard gas} \quad \times = \frac{\text{Area of sample}}{\text{Area of standard}}$$

$$\times = \frac{\text{Volume of standard injected}}{\text{Volume of sample injected}}$$

$$\times = \frac{\text{Volume of gas evolved in litres}}{\text{Volume of oil in litres}}$$

3. 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 this analysis is taken as a reference value/bench mark. Results of later periodic analysis are compared with the bench mark for each transformer. CLW vide letter no. ELDD/3254/part dated 27.08.2021 advised to all OEMs of transformer that DGA report is to be submitted to respective inspecting agency during routine inspection and same is to be provided to ZRs/Sheds as and when required. Therefore, same report shall be treated as reference by ZRs/Shed for interpretation of subsequent DGA result.

4. ESTABLISHMENT OF NORMS.

4.1 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 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	4-10 years in service	More than 10 years in service
Hydrogen (H2)	100/150	200/300	200/300
Methane (CH4)	50/70	100/150	200/300
Acetylene (C2H2)	20/30	30/50	100/150
Ethylene (C2H4)	100/150	150/200	200/400
Ethane (C2H6)	30/50	100/150	800/1000
Carbondioxide(CO2)	3000/3500	4000/5000	9000/10000

4.2 Further to this, IEC: 60599 (2022)/IS 10593:2023 provides a method to interpret DGA results based on ratios of basic gases for power transformers used in power system which can also be used for interpretation of DGA results of Main transformer for Electric Locomotives.

Case	Characteristic Fault	Ratio of C2H2 / C2H4	Ratio of CH4 / H2	Ratio of C2H4 / C2H6
PD	Partial discharges(see Notes 3 and 4)	NS[a]	< 0.1	< 0.2
D1	Discharges of low energy	> 1	0.1 to 0.5	> 1
D2	Discharges of high energy	0.6 to 2.5	0.1 to 1	> 2
T1	Thermal fault t < 300ºC	NS[a]	> 1 but NS[a]	< 1
T2	Thermal fault 300ºC < t < 700ºC	< 0.1	> 1	1 to 4
T3	Thermal fault t >700°C	< 0.2[b]	> 1	> 4

NOTE 1 – In some countries, the ratio C_2H_2/C_2H_6 is used, rather than the ratio CH_4/H_2. Also, in some countries, slightly different ratio limits are used.

NOTE2 –The above ratios are significant and should be calculated only if at least one of the gases is at a concentration and a rate of gas increases above typical values.

NOTE3 – CH_4/H_2 <0.2 for partial discharges in instrument transformers. CH_4/H_2 < 0.07 for partial discharges in bushings.

NOTE4–Gas decomposition patterns similar to partial discharges have been reported as a result of the decomposition of thin oil film between overheated core laminates at temperature of 140°C and above.

[a]NS = Non- significant whatever the value.

[b] =An increasing value of the amount of C_2H_2 can indicate that the hot spot temperature is higher than1000°C.

Typical Faults in Power Transformer

Type	**Fault**	**Examples**
PD	Partial discharges	Discharges in gas-filled cavities resulting from incomplete impregnation, high humidity in paper, oil super saturation or cavitation and leading to X-wax formation
D1	Discharges of low energy	Sparking or arcing between bad connections of different or floating potential, from shielding rings, toroids, adjacent disks or conductors of winding, broken brazing or closed loops in the core. Discharges between clamping parts, bushing and tank, high voltage and ground within windings, on tank walls. Tracking in wooden blocks, glue of insulating beam, winding spacers. Breakdown of oil, selector breaking current.
D2	Discharges of high energy	Flashover, tracking, or arcing of high local energy or with power follow-through. Short circuits between low voltage and ground, connectors, windings, bushings and tank, copper bus and tank, windings and core, in oil duct, turret. Closed loops between two adjacent conductors around the main magnetic flux, insulated bolts of core, metal rings holding core legs.
T1	Thermal fault t < 300ºC	Overloading of the transformer in emergency situations. Blocked item restricting oil flow in windings. Stray flux in clamping beams of yokes.
T2	Thermal fault 300ºC < t <	Defective contacts between bolted connections (particularly between aluminium bus bar), gliding contacts, contacts within

	700ºC	selector switch (pyrolitic carbon formation), connections from cable and draw-rod of bushings. Circulating currents between yoke clamps and bolts, clamps and laminations, in ground wiring, defective welds or clamps in magnetic shields. Abraded insulation between adjacent parallel conductors in windings.
T3	Thermal fault t >700°C	Large circulating currents in tank and core. Minor circulation currents in tank walls created by a high uncompensated magnetic field. Shorting links in core steel laminations.

5. DIAGNOSIS OF FAULTS.

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

Characteristics gases associated with various faults are as under:-

Sl. no.	Dissolved Gases	Associated Faults
1.	Methane (CH4)	Low temperature hot spot.
2.	Ethane (C2H6)	High temperature hot spot.
3.	Ethylene (C2H4)	Strong over-heating.
4.	Acetylene (C2H2)	Arcing
5.	Hydrogen (H2)	Partial discharge
6.	Carbon dioxide(CO2) & Carbon-monoxide(CO)	Thermal decomposition of paper insulation

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.
- 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.

6. PROCEDURE FOR FAULT DIAGNOSIS

6.1 Obtain the results of concentration of various gases in terms of micro litre per litre(ppm).

6.2 Compare the concentrations with sensitivity limits. These should be at least ten times the sensitivity.

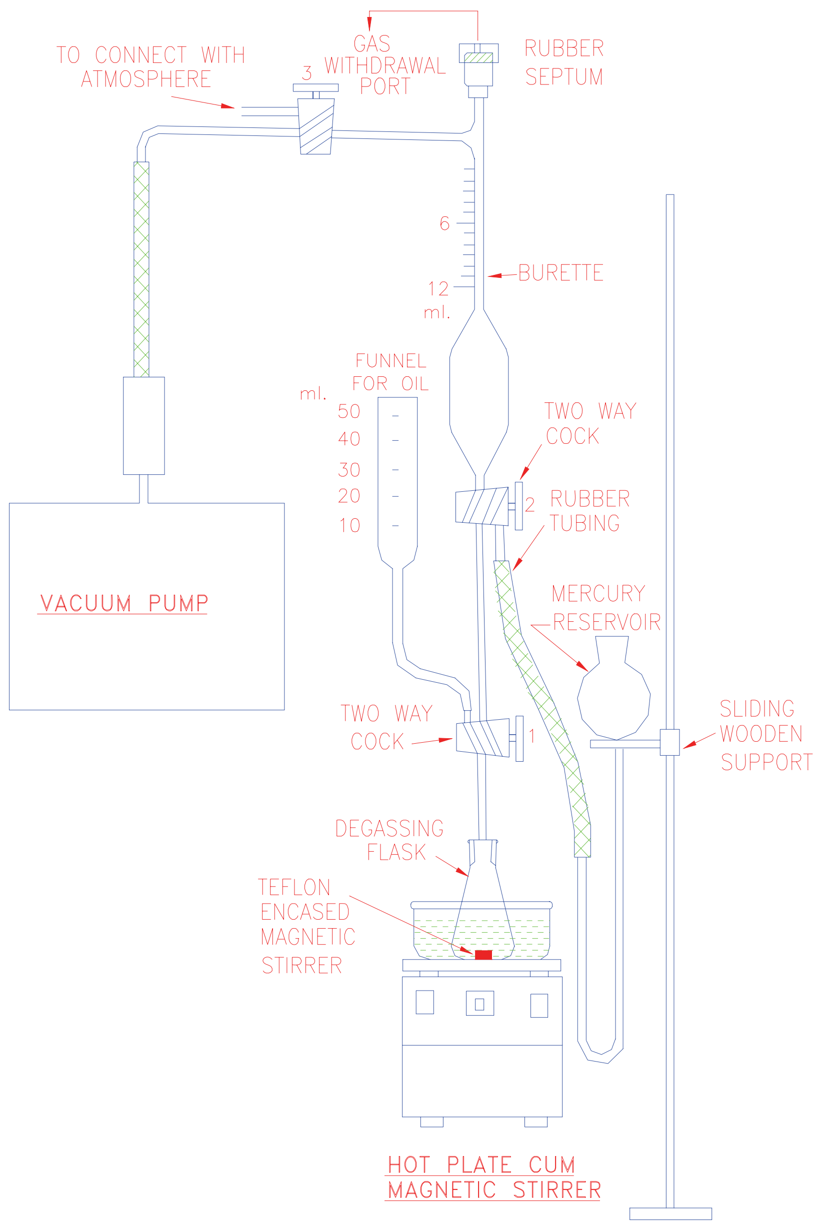
6.3 If it exceed sensitivity limits, compare with bench marks in line with clause no. 3 above.

6.4 If it exceed bench marks, compare gas concentration values with norms given in para 4.1 depending upon age and design of transformer.

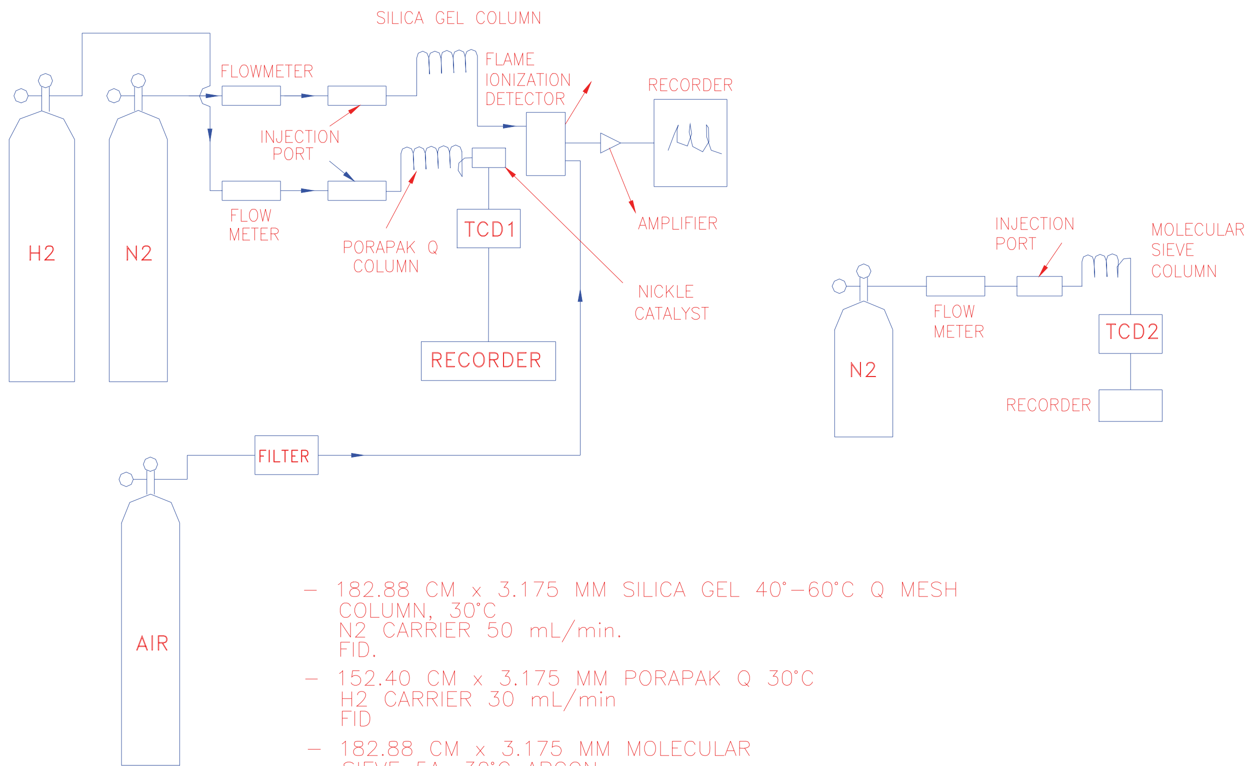
6.5 Also the basic gas ratio may be calculated and should be compared with values given in para 4.2.

6.6 Once the interpretation is made, necessary action to be initiated.

ANNEXURE: II



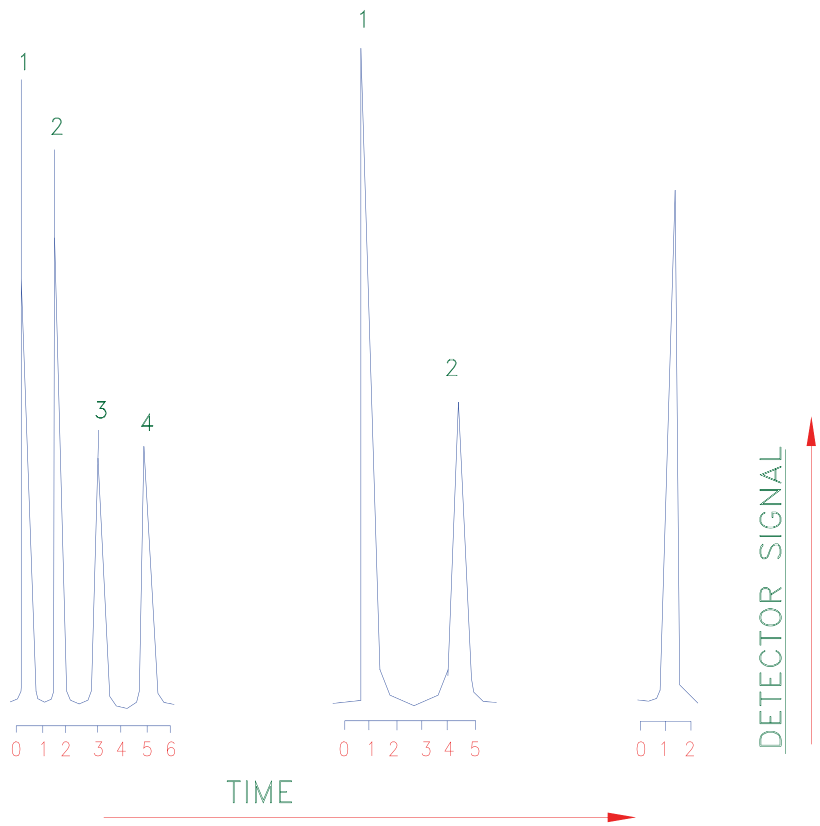
GAS EXTRACTION SYSTEM



- 182.88 CM x 3.175 MM SILICA GEL 40°–60°C Q MESH
  COLUMN, 30°C
  N2 CARRIER 50 mL/min.
  FID.
- 152.40 CM x 3.175 MM PORAPAK Q 30°C
  H2 CARRIER 30 mL/min
  FID
- 182.88 CM x 3.175 MM MOLECULAR
  SIEVE 5A, 30°C ARGON
  CARRIER 50 ml/min
  TCD

FIG –1

TYPICAL ARRANGEMENT IN A GAS CHROMATOGRAPH



FID
COLUMN : SILICA GEL

1. METHANE (CH4)
2. ETHANE (C2H6)
3. ETHYLENE (C2H4)
4. ACCETYLE (C2H2)

T.C. D1
COLUMN : PORAPAK Q

1. AIR
2. CO2

T.C. D1
COLUMN : MOLECULAR SIEVE

1. H2

FIG. 2

SAMPLE STRIP CHART RECORDING