CONTROLLING OIL SAMPLING TO ENSURE PLANT AND OPERATOR SAFETY

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Gordon Noble

Transaudit Pty Ltd
West Lakes, SA 5021 Australia
E-mail: gordon@transaudit.com.au

Abstract: Transaudit have developed an oil sampling system with its *Trans-Sample Coupling* that ensures no air can enter the transformer during the sampling process. This system ensures that - even if the sampling hose is removed without closing the main valve - no oil will escape from the equipment being sampled, and every sample is repeatable. This connection to the transformer, on-load tap changer or oil circuit breaker is a static connection, that remains on the equipment for its entire in service life. This in turn eliminates the issue of sample cross contamination due to poor sampling techniques, and field technicians can reduce the amount of equipment being transported for their work, and eliminate delays arising from a technician lacking the correct reducers and flanges. All transformers can be safely checked as to whether or not a sample can actually be taken without the risk of a transformer under vacuum sucking in air when the sampling valve has been opened. Development of this sampling device occurred over 12 months with trials of different designs being tested under vacuum and under pressure to ensure durability of the device.

Keywords: Dissolved Gas Analysis, Oil Sampling, Repeatability, and Quality Control

1. INTRODUCTION

The IEC and IEEE have repeatedly discussed the need for correct methods for taking oil samples for the purpose of Dissolved Gas Analysis (DGA) and oil quality testing.

These methods are covered in guides and standards, and in general most companies taking oil samples follow these recommendations. Laboratories supply glass syringes and bottles, and field technicians take oil samples using sampling tubes through various methods. Often overlooked however is the need for consistency in the connection to the transformer, and the necessity of cleanliness in all aspects of the sampling process.

This is briefly referenced in various IEC Standards with statements like *"clean with a lint free cloth"* or similar; however these statements do not cover all the required actions needed for producing repeatable oil samples. The field technician has to deal with and cater for numerous variations in equipment, including multiple different valves, flanges and fittings - for them to succeed in sampling transformers, on-load tap changers and oil circuit breakers.

Routinely, this will involve the technician needing to possess a box of connectors that are shared between all of the aforementioned equipment types. Generally, these connectors aren't cleaned between each sample taken, relying on the wash effect of the flush to clean the connector being used.

Figure 1 demonstrates a field technician's fitting box. This particular technician is responsible for sampling upwards of sixty transformers, and an equal number of On Load Tap Changers annually. He also samples up to one hundred distribution transformers, and performs retests during the year. When not in use, such boxes will generally sit in a workshop.

Figure 1. Oil sampling connectors within a field technicians fitting box.

Transaudit's field technicians have been using a hydraulic quick coupler system for sampling over a number of years, and this lead us to look at just what is required to build a robust device for this purpose that would withstand the test of time, giving particular attention to the sealing faces of the coupler.

In our operations, we noted that transformer oil had an adverse effect on the sealing faces of our technicians sampling connectors, meaning they only had a lifecycle of between three to four months between replacement.

Additionally, we observed the transformer oil created a sludge that would clog up connectors, which in turn would cause the connector to weep oil. In fairness, Transaudit technicians would operate these connectors far more often than the connectors were designed for during their three to four month average lifecycle; so our bespoke design had to deliver higher than normal usage - even though the intention was to leave the connector on the transformer for life.

Once an initial design was prepared, our draftsman found a connector model that was close to our requirements. With the aid of 3D modelling software and a very proactive machining company, we built our first prototypes of the *Trans-Sample Coupling*. Testing of the coupling identified the need for additional modifications, to ensure the maximum possible volume of trapped air is removed from the connection area.

After these modifications were validated through testing, we built our first sample batch of couplings.

Figure 2. The coupler bodies being machined.

Once manufactured, these devices needed to be connected to a transformer, so we decided to standardise the coupling size to a 1" BSP thread by use of an adaptor bush. As the couplings have used tapered threads to ensure sealing, no "off the shelf" item existed for this need - leading to further design and manufacture by Transaudit in partnership with the same machining company building our coupling systems.

Figure 3. Newly machined adaptors.

Soon, with many of our customers - across industries such as Electricity generation/supply/distribution/transmission, Renewable Energy, Industrials, Refineries, Manufacturing and Transportation/Freight (Air, Rail) now using our couplings - it became quickly apparent how much we had underestimated the time/cost savings. In some cases, previous oil sampling times had been cut by more than half - this alone vindicating the installation cost of the *Trans-Sample Coupling system*.

Quality of the oil testing had improved dramatically. We saw that through cross contamination – particularly Acetylene, one customer had this gas completely disappear from their oil results during our trials.

In the following example (Table 1), you will see that the gasses being detected by dissolved gas analysis have flattened out indicating two things.

First, repeatability. The oil sample being provided to the laboratory is of sufficient quality that results being provided back are consistent and accurate.

Second, the quality of the laboratory providing the dissolved gas analysis.

It is important to note that samples 4 to 8 were tested by laboratory "x"; samples 4 and 8 were sampled by the customer; 5, 6 & 7 sampled by a subcontractor. Samples 1, 2 & 3 were tested laboratory "y" – Transaudit's choice.

We believe that samples prior to October 15 were taken immediately after the OLTC had been sampled – this belief based upon the transformer having a large flange connection, whereas other transformers on site and the OLTC oil connection points are all 1" BSP type connections. The substations located geographically either side of this substation have 1" BSP type connections on transformers and OLTC, so we believe it is safe to assume that the sampling order assumed is correct.

In the following table, it is also important to note that Acetylene has departed from the oil results from 2015 to 2017, Hydrogen also levelled, and other heating gasses show a more balanced production.

There's no doubt that there is an overheating issue in this transformer, but what we know about the transformer is:

1. There has been no processing, topping up or filtration of the oil;
2. The OLTC is operating at similar monthly operations as it has been for the data sample period; and
3. The use of a coupling system during sampling, using clean and new sample tubes for each sample, and ensuring correct sampling methods has taken the transformer from critical to abnormal operation without any invasive actions required.

Sample Date	H2	CH4	C2H6	C2H4	C2H2
Apr-17	94	8	6	13	<1
Nov-16	99	7	4	10	<1
Oct-15	96	6	5	11	<1
Nov-14	158	1	14	25	7
Nov-13	22	8	3	13	9
Sep-12	77	19	5	9	12
Nov-11	2	6	19	22	1
Sep-10	85	7	9	2	3

Table 1. Trial data (orange) vs previous data (black)

2. RELATED WORK

In conjunction with the development of the *Trans-Sample Coupling*, Transaudit also developed a one-way valve system for the safe removal of oil to eliminate any chance of air being sucked back into the equipment where it is a sealed system under vacuum.

By using a number of commercially available items, we created a simple but effective sampling connector to serve this purpose. The connector has the standard *Trans-Sample Coupling* male end fitted, and can be used either as an indicator of vacuum alone or as an integrated part of the sampling tube.

Using a simple pressure check, we tested a number of different non-return valves at 100kPA. This value being representative of one normal atmosphere of pressure against the internal mechanical seal. Of all the specimens tested over the space of a week, only one passed which was then used in our final design.

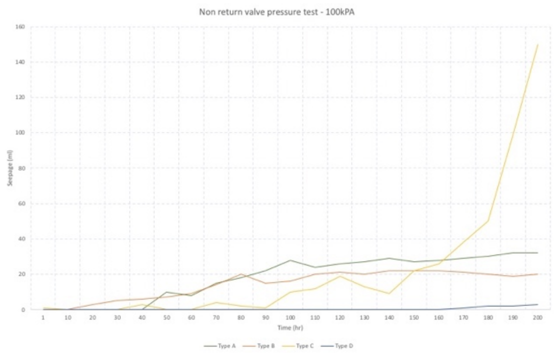

Figure 4. Non-Return Valve Pressure Test

3. WHY SHOULD I BE CONCERNED ABOUT THIS?

the various components of taking an oil sample for DGA from a transformer break down into five areas, being:

1. Operator and plant safety,
2. Repeatability of samples,
3. Quality of the oil reaching the laboratory,
4. Quality of the laboratory testing the oil, and
5. The cost of taking the sample, testing and analysis.

All these components directly relate to controlling the quality of the oil sample being taken.

3.1 Operator and plant safety

There are many standards available that instruct the technician on how an oil sample should be taken, including IEC 60475 and 60567, ASTM D 923 and 3613. Transformer manufacturers and testing laboratories including ABB, Doble, Siemens also make available documentation, papers and training videos covering how sampling should be taken,.

However, all the aforementioned materials only made brief mention of the actual connection onto the transformer.

To ensure operator safety, field technicians must take all necessary steps to stop air rushing into the equipment being sampled that could result in an immediate flashover or impacting equipment safety by stopping air entering the system and finding high points to congregate as large air bubbles, which in turn adversely affects the insulating properties of materials being designed as oil immersed.

ASTM D923 talks about transformers under negative pressure and using the slug method – a small amount of oil in the sampling tube and watching which way it moves when opening the main valve. However, this method still allows air to enter the transformer, and - if either the technician is not fast enough, the valve operation is slow or refuses to close once opened - disaster is only seconds away.

3.2 Reliability of samples

Quality of oil samples is the foundation to accurate diagnosis of equipment being sampled. DGA is the science of deconstructing a sample provided to extract hydrocarbon gasses (C_3H_6, C_3H_8, H_2, CH_4, C_2H_6, C_2H_4, C_2H_2), carbon gasses (CO, CO_2), Furanic Compounds (5H2F – oxidation, 2FOL – moisture, 2FAL – overheating, 2ACF – voltage spike, 5M2F – sever overheating), Oxidation Inhibitor, Acids, and a myriad of other compounds, molecules and particles. The standard unit measurement is parts per million (PPM). This is a very difficult number to comprehend for most people.

Consider the following image. There are $10^1 x 10^1 = 10^2$ (100 dots per block) and there are $10^2 x 10^2 = 10^4$ (10,000 dots in the image). Of these 10,000 dots shown, 10 are red in colour. This represents 10 parts per 10 thousand. Consider now increasing the image size to $10^3 x 10^3 = 10^6$ (1,000,000 dots) and finding the 10 red squares. 10 parts per million – if that was C2H2, it could well be the trigger to de-energise a transformer.

Now consider the residue oil that is carried over from one sample to another by dirty fittings, caught in threads, still in the sampling tube, wiped on by “lint free rags”, carried over by a flange gasket or even the technician’s dirty gloves.

The ease of cross contamination is staggering and the number of false positives through contamination is astounding according to sources such as Doble and Weidmann[1] – leaders in this field.

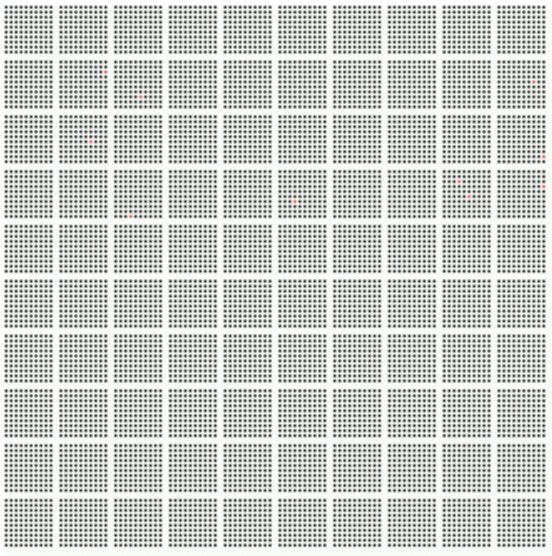

Figure 5. 10,000 dots

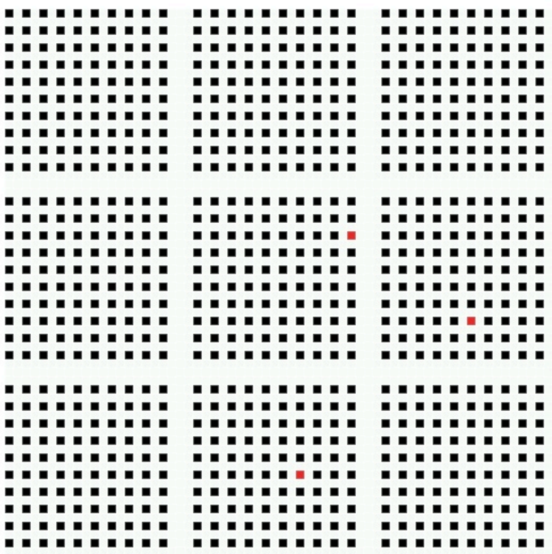

Figure 6. 900 dots showing 3 red dots (first 3x3 from above)

3.3 Quality of oil reaching the laboratory.

The first consideration should be the sample container. IEC, ASTM, IEEE all have recommendations on the best methods to retrieve and store oil samples. Our recommendation is always glass. Glass syringe for a 50ml sample, from which DGA, Moisture and Acid can be tested; and 500ml amber glass bottles for all other tests. Both syringe and bottle need to be treated with respect as soon as the sample is completed, with immediate removal from direct sunlight, and an expedited process to the laboratory.

Transaudit does not use plastic bottles due to their poor performance in providing quality samples. In 2016 we considered the use of 750ml PET amber bottles to lower sample transport costs, particularly between New Zealand and Australia.

Conclusive studies conducted by Powerlink Laboratories into quality degradation of oil samples stored in plastic over time (with a focus on breakdown voltage and moisture, showed that - in all cases (n=20) - the quality of the oil decreased at alarming speeds. At 11 days after sampling the plastic bottle was ~68% less breakdown voltage than the glass bottle control sample, and moisture was 123% greater than the glass bottle control sample.

Anecdotal evidence points to an average of 12 days between sample and initial laboratory processing across both Australia and New Zealand - so if supplied samples are in plastic, false positives are a probability.

3.4 Quality of the testing laboratory

One can judge a laboratory on their ability to repeat sample results. If all steps are being taken to ensure that the best possible quality sample is being obtained, one should expect then that the laboratory

[1] LIfe of a Transformer Seminar, Orlando FL, 2007

testing this oil will be repeatable in all tests. We like to say – "test the testers" by using a "true north" oil sample – one which has known gas levels – companies such as Morgan Schafer sell these samples, so if in doubt, test the laboratory.

Such a testing methodology should ensure the laboratory is testing the oil in a timely manner with minimal stand time – that is the oil standing on a bench awaiting test after arrival at the laboratory. Samples should be stored in a humidity and temperature-controlled room at all times for a minimal period before being tested.

Also evaluate the redundancy in the laboratory. If a DGA Analyser or Voltage Breakdown cell needs repair or calibration, what impact will that have on your samples and the additional standing time they will endure if there is no equipment redundancy. Remember that oil decays quite fast, thus time is of the essence for ensuring quality results.

Finally, assess the quality and type of equipment that the laboratory is using. Gas scouring, headspace technology or vacuum gas rack all offer different results. Understand that not all testing methods and equipment is created equal with outputs and repeatability, and this should be a serious consideration when choosing your testing laboratory.

Figure 7. Over 300 samples being checked into a laboratory by Transaudit.

3.5 Costs of taking the sample, testing, and analysis

With numerous companies offering sampling services, the need to ensure the sample being sent to the laboratory is of upmost quality is more now than ever. The use of the sampling coupling is the easiest and most cost-effective way to ensure that quality is as close to perfect each time as is achievable.

Let's consider the costs associated with taking a DGA sample from a single transformer with OLTC. Let's assume there's no travel involved, the technician walks out to the substation from his office.

Labour	85.00
Materials	10.00
Packaging and shipping	35.00
DGA Analysis (TX + OLTC)	155.00
Evaluation / Engineering	45.00
Total Sample Cost	330.00

Figure 8. Typical DGA sampling cost

All situations will be different of course, labour costs will change between locations and companies, but in essence this is a good reflection of how costs build. If the sample arrives at the laboratory and is not good quality, a couple of things can happen.

First it may be misinterpreted by the laboratory as being a trend change for the worse and reported as such, or secondly, it will be rejected by the laboratory as being a poor sample and a retest is required.

Labour	85.00
Materials	10.00
Packaging and shipping	35.00
DGA Analysis	155.00
Evaluation / Engineering	45.00
Additional engineering time because of poor sample	45
Labour for 2nd sample	105.00
Materials for 2nd sample	10.00
Packaging and shipping 2nd	35.00
DGA Analysis 2nd	155.00
Engineering evaluation 2nd	25.00
Total Sample Cost	725.00

Figure 9. Typical DGA sampling cost with retest

Sampling time is now taking longer on the second sample due to the technician now being far more critical of his process, engineering taking more time to analyse results guaranteeing no false positives – it's quite a leap up in cost.

A Transaudit customer – a network utility with 25 zone substations, some around 80km apart, oil sampling would previously take around 4 days which included OLTC's and a number of single phase banks with spares. In 2017 this customer installed the Trans-Sample coupling on all equipment including OLTCs. The cost of sampling and installation of the couplings increased their annual sampling spend by around 55% in 2017 with a view of recovering the installation costs through time savings spread over 2018, 2019 and 2020.

In 2018, the annual oil sampling was conducted in 2 days – this was a 50% reduction in time and this time saving led to the recovery of the Trans-Sample couplings installation costs in the first year of use.

This exact same model was also experienced by a metro rail customer who have also halved their sampling time across their suburban rail network.

4. DESIGN AND INSTALLATION

A key feature of the coupling is during the mating of the male and female components, the air which is normally trapped (when using existing methods such as screwed fittings or flanges) that frequently ends up inside the transformer during valve opening, is forced out around the male coupling which is an integral part of the component design.

When the two components of the Trans-Sample coupling finally mate, the amount of air remaining in the coupling is estimated at around 6-10mm^3. This is at worst a very small bubble which is still in the coupling.

When correctly fitted to the equipment, a vacuum is applied on the newly installed coupling for two reasons. First to check the integrity of the installation and secondly to remove any air that is caught between the main valve and the coupling. This vacuum is then displaced with the equipment's oil by opening the main valve onto the vacuum. This ensures that there will never be air between the sampling point and the transformer other than the previous mentioned very small bubble. The main transformer valve stays in a normally closed position when not sampling and is only opened and closed during the sampling process.

5. OPERATION AND SAMPLING

The operation of the coupling requires two normally closed sealing faces to be pushed open. These machined faces are held closed with high tension springs and retainers which are opened when two dimples are pressed together during the mating of the female and male components of the coupling.

The internal components of either side of the couplings are in a captured environment where any failed component of the coupling will remain in place with little to no chance of this failed component able to enter the equipment. As both the female and the male halves have this sealing arrangement, the accidental removal of the male component during sampling or the field technician mistakenly leaving the transformer valve open ensures no oil will escape from the equipment being sampled.

Dust and other pollution is kept out of the coupling by either a plastic sealing bung for indoor use or an aluminium sealing bung for outdoor use. All both sides of the coupling are laser engraved showing the company name – this is to ensure that no foreign male coupling is used in place of the original item and possibly cause damage to the female component.

5.1 Sampling

A technician will arrive to sample with their new tool kit comprised of just a sampling tube, thermometer, bottles, syringe, rags and waste oil bucket. Information is obtained such as oil temperatures and serial number then the technician then proceeds to take the sample. First the main transformer valve is opened. The sample tube is unpackaged and with one end in the bucket, inserted into the coupling. The oil will flow immediately and this can be controlled by the addition of a small sampling valve or by using the main transformer valve to stem the oil flow. As this is a clean system, the amount of flush oil is significantly reduced in transformers unless the coupling has been installed at the very bottom of the tank.

The syringe is attached using the Luer Lock attachment that comes standard on Transaudit supplied sample hoses and the syringe stopcock set to bypass. Oil then flows through the bypass into the bottle. On completion of the bottle fill(s) the stopcock is rotated to allow the oil flow into the syringe and depending on which method the technician prescribes to, a 50ml sample will quickly follow. Importantly, the male sampling tube is now removed from the coupling before the main valve is closed, the valve being closed once the male sampling tube is gone. The dust cap is reinserted into the coupling and the job is completed in record time.

Figure 8. A Transaudit technician taking a syringe sample from a 60MVA Transformer

6. CONCLUSION

A poor-quality oil sample results in the loss of revenue and can potentially lead to the loss of a transformer, OLTC or oil circuit breaker due to missing an incipient

fault in said equipment. With the installation of a coupling system such as the Trans-Sample coupling, poor-quality samples can be a thing of the past, free air entering the transformer during sampling can be eliminated, and quality oil samples can be guaranteed.

Cost savings are real, the recovery of costs associated with the installation of a coupling system is very fast through future time savings, and the probability of failure of equipment through false positive becomes negligible if a quality process is in place.

Our development of the coupling system has been stringent with clear outcomes required for the final product of which we have met and exceeded. Off the shelf components are not designed for the harshness of a transformer environment and any development of a coupling system needs to be with this in mind.

The future of oil sampling is in a state of flux at the moment with a couple of companies doing parallel development and research in this field. We have purposely kept our components solid and robust with longevity of the coupling in mind.

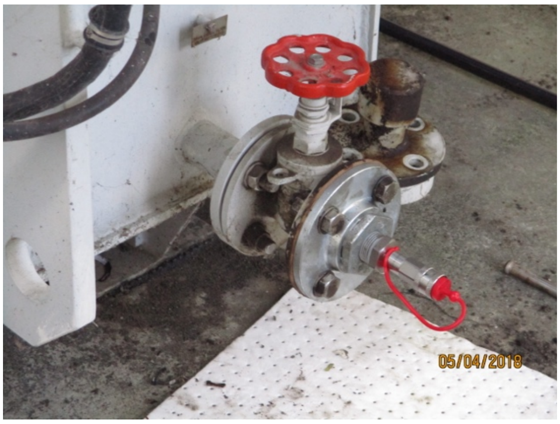

Figure 9. An installed coupling

7. REFERENCES

1. ASTM D 3487 - Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus in Electrical Insulating Liquids and Gases

2. IEC 60475 - Method of sampling insulating fluids

3. IEC 60567 - Oil-filled electrical equipment – Sampling of gases and of oil for analysis of free and dissolved gases – Guidance

4. IEC 60599 - Mineral oil-impregnated electrical equipment in service – Guide to the interpretation of dissolved and free gases analysis