B. TECH. PROJECT REPORT

On

Shape memory alloy based Micro-circuit breaker for Transformer oil Temperature sensing

BY

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DISCIPLINE OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

December 2016

Shape memory alloy based micro-circuit breaker for transformer oil temperature sensing

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
in
MECHANICAL ENGINEERING

Submitted by:
Chandan Kumar
Parikshit Gaur

Guided by:
Dr. I.A. Palani
Dr. B.K. Lad

INDIAN INSTITUTE OF TECHNOLOGY INDORE
December 2016

CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Shape memory alloy based micro circuit breaker for transformer oil temperature sensing"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Mechanical Engineering' completed under the supervision of **Dr I.A. Palani (Associate professor, Mechanical Engineering), & Dr. B.K. Lad (Associate professor, Mechanical Engineering),** IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

Signature and name of the students with date

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of our knowledge.

Signature of BTP Guides with dates and their designation

Preface

This report on “Shape memory alloy based micro circuit breaker for transformer oil temperature sensing" is prepared under the guidance of Dr. I.A. Palani & Dr. B.K. Lad.

Through this report, we have tried to give a detailed analysis of temperature sensing mechanism for transformer oil using Shape memory.

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner. We have also added graphs and figures to make it more illustrative.

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Acknowledgements

We wish to thank **Dr. I.A. Palani** & **Dr. B.K. Lad** for their kind support and valuable guidance. This work has been done in framework of the IIT Indore project that is funded by PRIUS (Promotion of Research & Innovation for Undergraduate Student). We would like to Acknowledge PhD scholar **Mr. Akash K,** Mechatronics & Instrumentation lab and Central Workshop of IIT Indore for providing their sincere cooperation and guidance to carry out this research.

It is their help and support, due to which we became able to complete the design and technical report. Without their support this report would not have been possible.

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Abstract

Power transformer is the one of the vital as well as one of the expensive elements in the electricity grid. Any malfunction of this element may affect the reliability of the entire network and could have considerable economic impact on the system. For several reasons, overloading of power transformers beyond their rating has been reported frequently. The primary issue leading to the failure of transformer is contamination of transformer oil by the working components due to prolonged high temperature exposure. Transformer oil temperature can be utilized as a primary parameter in monitoring the life of the transformer. At present, electrical approach for monitoring transformer oil temperature such as thermocouple and thermal resistor are being employed. However, these techniques are vulnerable to electromagnetic interference and are limited by sensors lifetime. Other non-contact techniques are ineffective due to difficulties in processing the output signal.

In this work a CuAlNi/Polyimide shape memory alloy composite has been applied to act as a temperature sensor in mineral oil. The composite film has been developed through thermal evaporation, which exhibit two-way shape memory effect. The developed films are employed in a custom-made oil rig and the suitability of using it as a circuit breaker in temperature sensing application has been explored. The circuit breaker can be triggered by measuring the displacement of the bimorph using optical methods such as laser displacement sensor or interferometer. The measurement is of non-contact type and the temperature can be monitored continually.

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Introduction

Electrical power transformer is a static device, which transforms electrical energy from one circuit to another without any direct electrical connection and with the help of mutual induction between two windings. It transforms power from one circuit to another without changing its frequency but may be in different voltage level. The working principle of transformer is very simple. It depends upon Faraday's law of electromagnetic induction. Actually, mutual induction between two or more winding is responsible for transformation action in an electrical transformer. Transformer oil helps in:-

- Provide an arc-quenching medium.
- It acts like insulation between the windings for which losses due to heating reduces.
- It reduces the humming noise created in transformer resulting in low vibration.
- The paper insulation provided on winding due to heat they melt and settle down at the bottom of the tank. The oil helps in preparing a sludge, which can be easily removed at the time of cleaning.
- It is also used as an indicator where the buckholtz relay senses the fault in transformer and gives a tripping signal.

All devices that use electricity give off waste heat as a byproduct of their operation. Transformers are no exception. The heat generated in transformer operation causes temperature rise in the internal structures of the transformer.

Transformer temperature rise is defined as the average temperature rise of the windings above the ambient (surrounding) temperature, when the transformer is loaded at its nameplate rating. A more efficient transformer generates less waste heat in the first place, but transformer temperature rise results from not only how much heat is generated but also how much heat is removed. Be careful that a unit carrying a low temperature rise figure is not also inefficient, using fans to remove the excess heat.

	Temperature rise limit for air as cooling medium	Temperature rise limit for water as cooling medium	Condition
Winding	55^0C	60^0C	When oil circulation is natural
	60^0C	65^0C	When oil circulation is forced
Top Oil	50^0C	55^0C	When transformer is sealed & equipped with conservator tank
	45^0C	50^0C	When transformer is neither sealed nor equipped with conservator tank

Table 1: Maximum temperature allowed in different cases

Temperature is one of the prime factors that affect a transformer's life. In fact, increased temperature is the major cause of reduced transformer life. Further, the cause of most transformer failures is a breakdown of the insulation system, so anything that adversely affects the insulating properties inside the transformer reduces transformer life. Such things as overloading the transformer, moisture in the transformer, poor quality oil or insulating paper, and extreme temperatures affect the insulating properties of the transformer. Most transformers are designed to operate for a minimum of 20-30 years at the nameplate load, if properly sized, installed and maintained.

Property	Limit	Effect of Temperature Rise
Dielectric strength	30 kV (min.)	Decreases, due to contaminations, especially water
Water	35 ppm (max.)	With increase in temperature solubility of water increases in oil, then after cooling this becomes free water
Acidity	0.01 mg KOH/g oil (max.)	Increases, due to oxidation which results in sludge & varnish deposits
Viscosity	3.0 cSt at 100 °C (max.) 12.0 cSt at 40 °C (max.)	Decreases
Flash point	145 °C (min.)	Oil may catch fire
Pour point	-40 °C (max.)	
Power factor	0.05% at 25 °C (max.) 0.3% at 100 °C (max.)	Increases, due to contaminations (Polar)

Table 2 : Effect of Temperature rise on Oil properties

Transformer coils are immersed in oil and are isolated from the environment in order to keep them safe from corrosion and contamination. Due to its closed and complex structure, temperature sensing of the oil has been one the most challenging task.

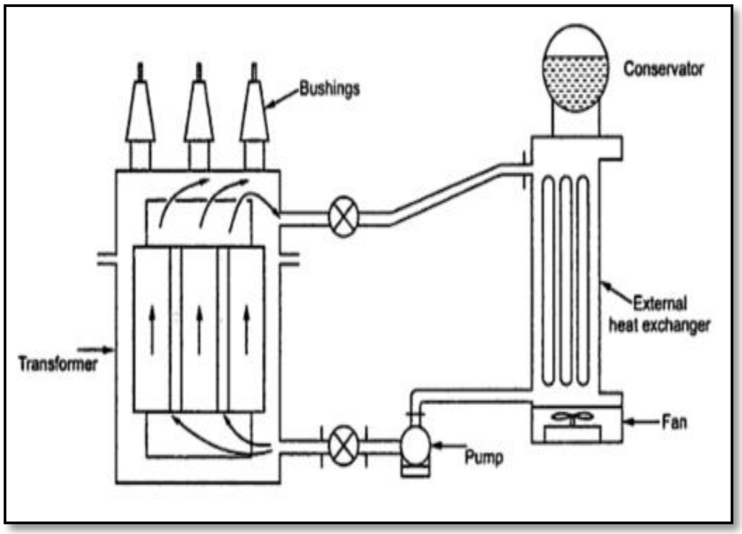


Fig. 1 Inside view of transformer

Through this project, we have been able to place the shape memory alloy in the hot spot region (maximum temperature region) to measure the highest temperature of oil by measuring the displacement of shape memory alloy.

To measure the temperature of transformer oil, two-way shape memory alloy has been used. Low temperature measurement has been done using Nickel-Titanium shape memory alloy while the high temperature measurement has been done using Copper-Aluminum-Nickel composite bimorph.

What is shape memory alloy?

A shape-memory alloy (SMA, smart metal, memory metal, memory alloy, muscle wire, smart alloy) is an alloy that "remembers" its original shape and that when deformed returns to its pre-deformed shape when heated.

Examples: NiTi, Cu-Al-Ni, Cu-Zn-Al

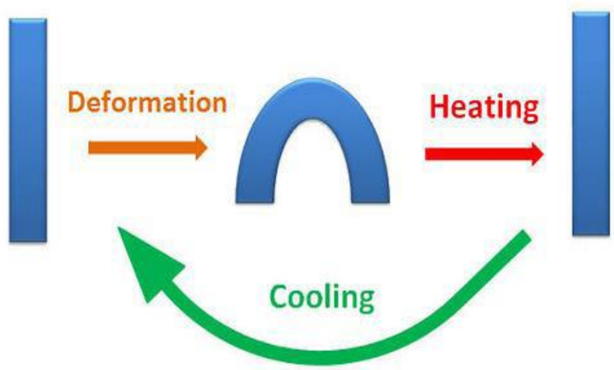


Fig. 2 Schematic of the shape memory effect of an SMA

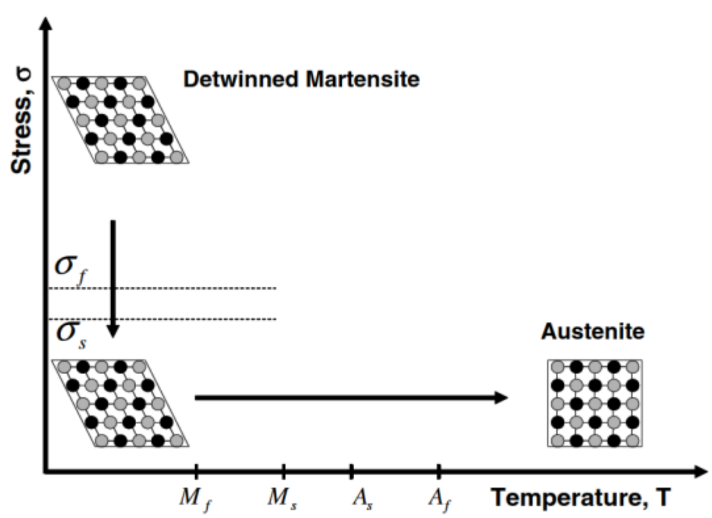


Fig.3 Showing the unloading and subsequent heating to austenite under no load condition.

When load is applied to shape memory alloy it changes from twinned martensite to detwinned martensite. When martensite is heated it change from martensite to austenite and when cooled in the absence of load it again change to martensite.

Properties of Shape memory Alloy

Some of the properties of Shape memory alloy that are advantageous for our experiment are:

- High force per unit volume or weight
- Light weight
- Compact
- Robust
- High corrosion resistance
- Frictionless
- Low maintenance
- Low energy requirement
- Its eliminates extraneous system like hydraulic, pneumatic, rotating part
- Transformation temperature of SMA can be varied by varying its composition

Ni-Ti Spring (40-90 °C)	**Cu-Al-Ni Bimorph (100-250 °C)**
NiTi is an alloy of Nickel & Titanium, where both are present roughly in equal atomic percentage.	It is a shape memory alloy of Cu-Al-Ni deposited on a polyimide sheet
Transformation temperature in range of 40-90 °C	Transformation temperature in range of 100-250 °C, can be changed by changing stoichiometry.
One way SMA	Two way SMA
Costly	Economical

Table-3 : Comparison between the Two SMAs

Experimentations and Analysis

Copper-Aluminum-Nickel Composite Bimorph has been used for high temperature measurement of transformer oil. Oil in the container was heated from the bottom using hot plate and the bimorph was held using clamp as shown in the image. Heating of the oil was done for 30 minutes followed by one hour cooling. Measurement of temperature of the oil was done using thermocouple and displacement measurement of bimorph was done using Laser Displacement sensor. Data were taken through Data Acquisition System interfaced to the computer. Graph of displacement verses time and temperature verses time was plotted.

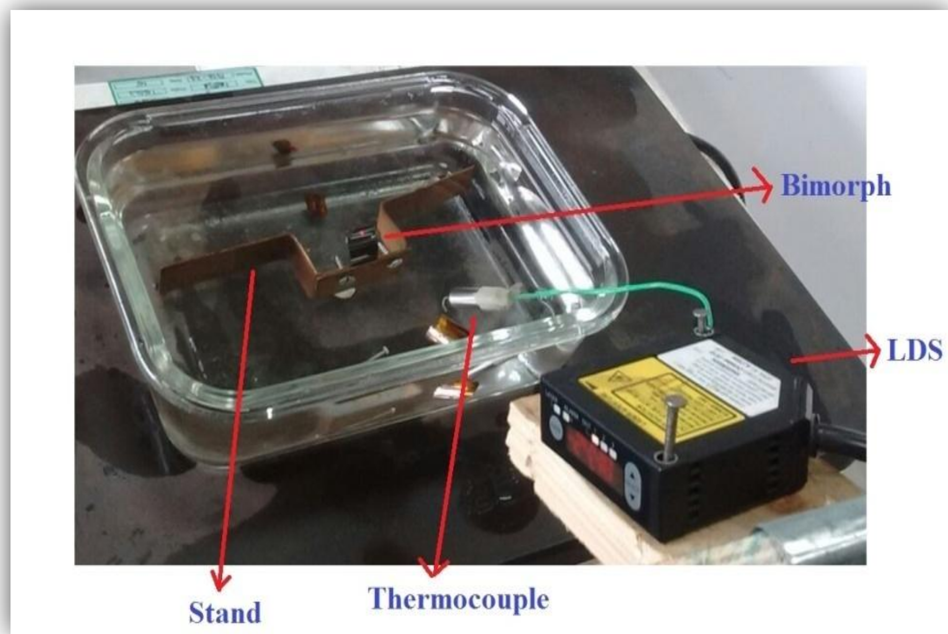


Fig. 4 Experimental setup to measure displacement of bimorph using LDS

Graphs obtained in case of Cu-Al-Ni Bimorph

Heating | Cooling

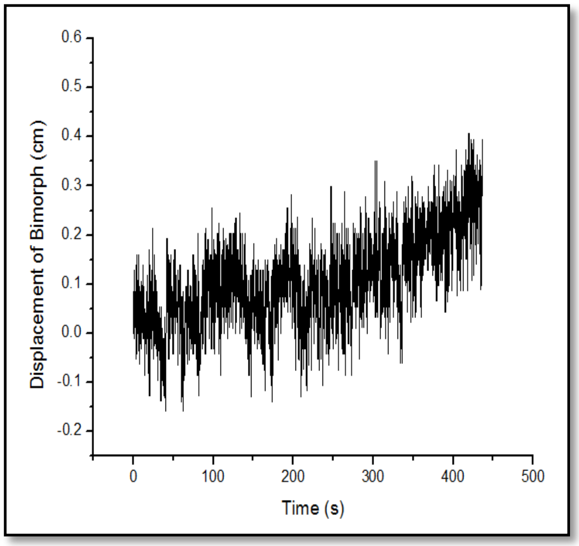


Fig.5 Displacement verse Time

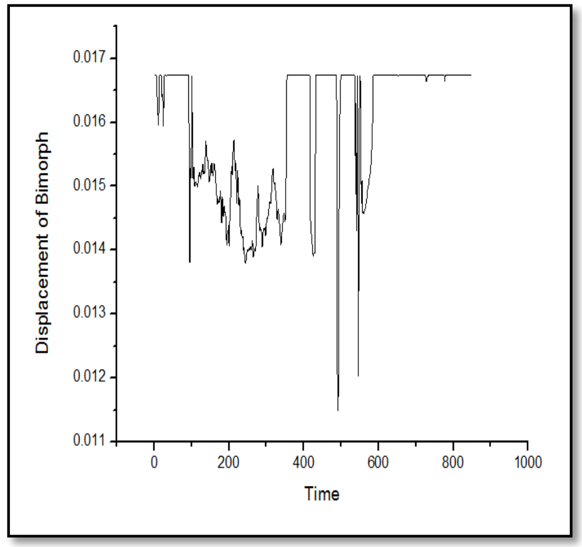


Fig.6 Displacement verses time

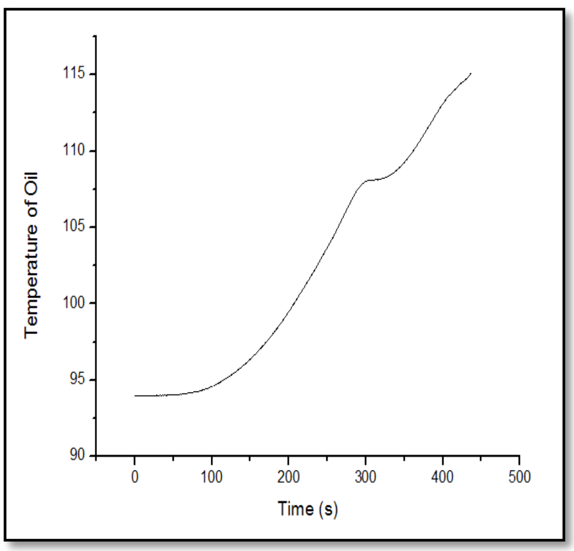


Fig.7 Temperature verses time

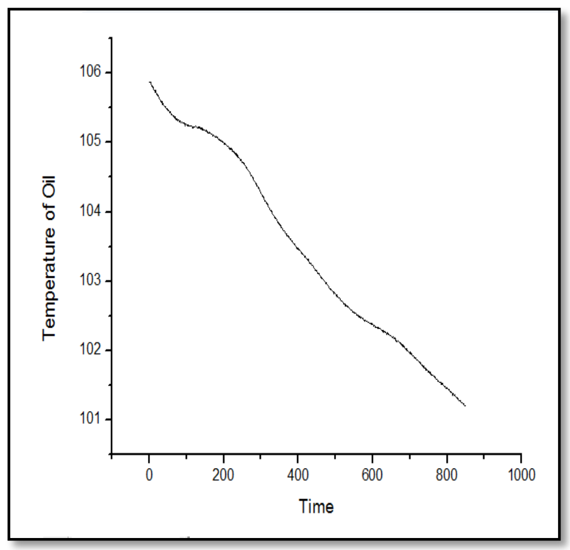


Fig.8 Temperature verses time

- ✓ Noise in first graph may be due to disturbance in the ambience or disturbance in the oil
- ✓ Peaks in the second graph is due to laser light not falling on its detector

Low temperature measurement with Ni-Ti Spring

Copper-Aluminum-Nickel bimorph has transformation temperature in the range of 90 °C to 250 °C. There was no significant displacement of Cu-Al-Ni bimorph below 80°C. Therefore, to measure the temperature below 90 °C we have used Nickel-Titanium shape memory alloy. The laboratory setup for the same is given below:

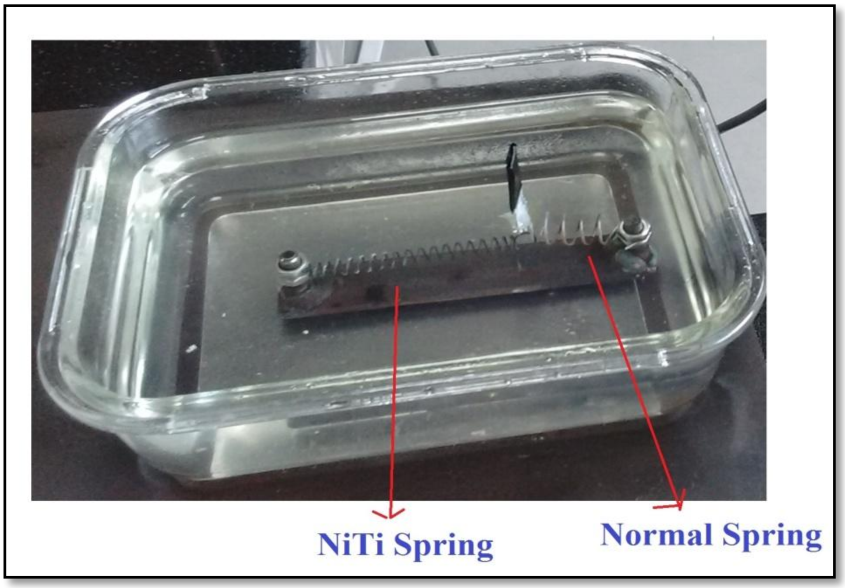


Fig.9. Experiment setup for Ni-Ti Spring

To provide an environment similar to transformer, an enclosed setup was built of galvanized Iron Sheet.

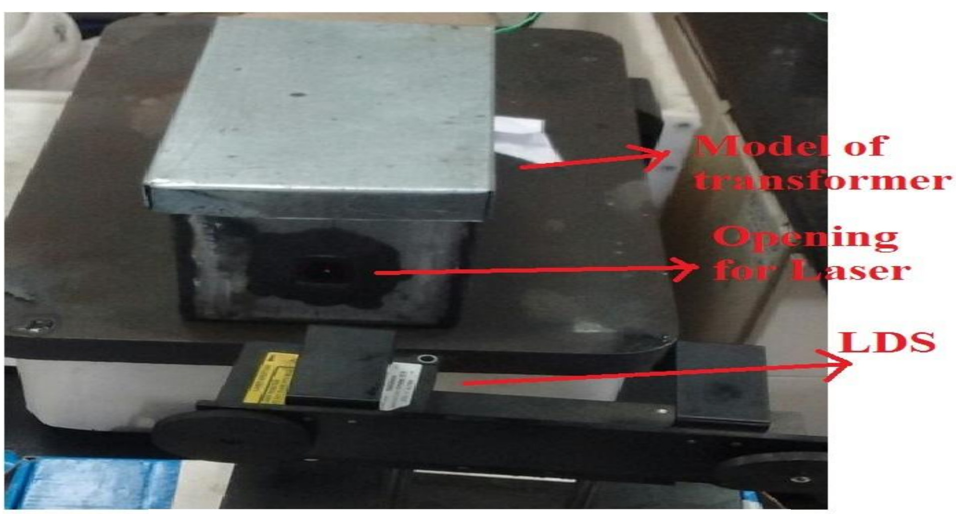


Fig.10 . Experimental Setup for NiTi Spring

Fig.7 Experimental Setup Similar to transformer environment

Displacement of Ni-Ti Spring was measured through the small opening provided in the box using laser displacement sensor. Data was collected similar as in case of Cu-Al-Ni Bimorph.

Graphs obtained in case of Ni-Ti Spring

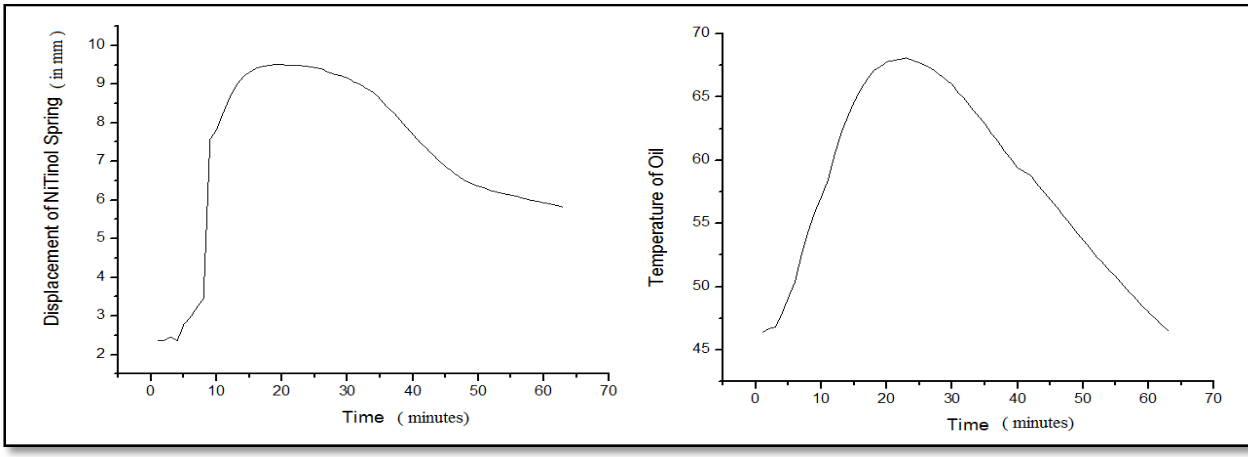


Fig.11 Thermocouple is attached to the NiTi Spring

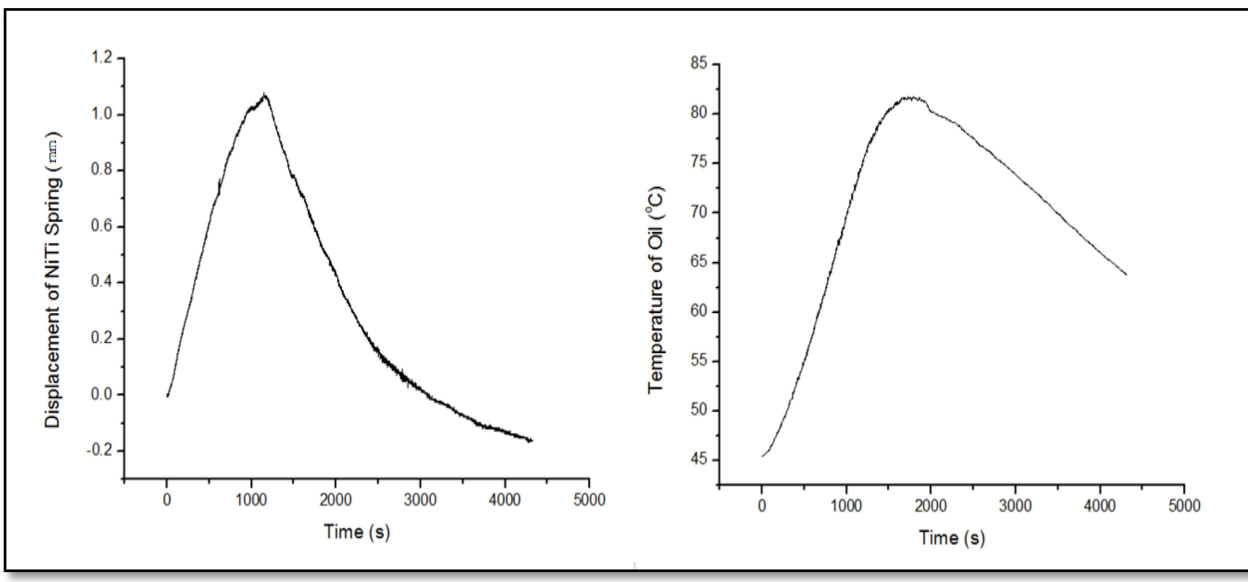


Fig.12 Thermocouple is 3 cm above Spring

- When thermocouple is above the NiTi spring (in Fig 9) there is a lag between the time when maximum displacement is noted and when maximum temperature is measured.
- This lag is due to the time taken for heat transfer in oil.

Contamination test of Transformer oil & its Effect on Actuation of Bimorph

Properties of transformer oil changes with time and temperature. Transformer oil mostly get contaminated due to dissolution of moisture from the environment which become free water when the oil cools down. Other contaminations include dissolved gases and sludge. Due to contamination flash point of the oil decreases considerably, hence it catches fire much below the anticipated value of temperature.

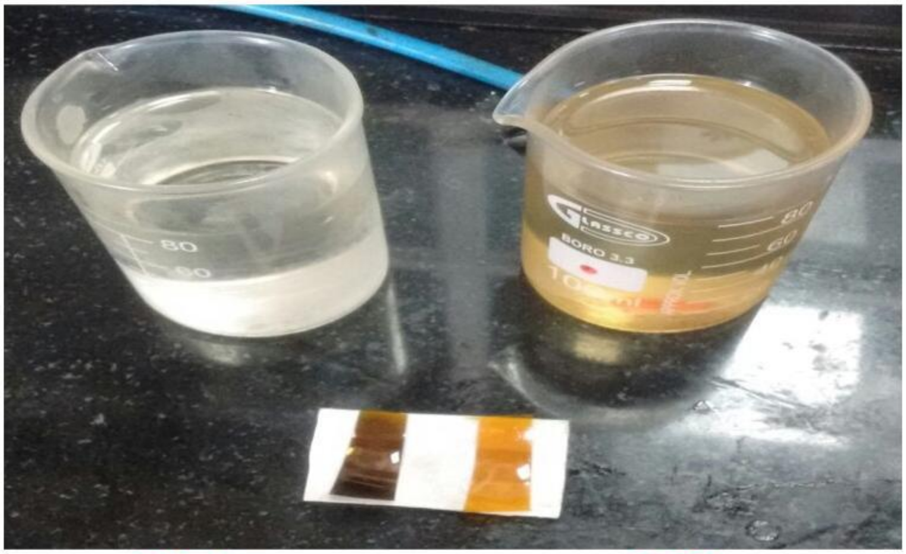
Accelerated test for Contamination due to moisture inclusion & acidity

Test for acidity:-

1 mL of 37% concentrated HCL acid was added to the transformer oil and was heated upto 100 °C. After few days the colour of oil changed from transparent to pale yellow and its flash point also decreased from 130 °C to 115 °C. 0.02 mg KOH/gm of oil was introduced.

Test for moisture effect:-

2 mL of water was added to 80 mL oil and was heated upto 100 °C and was kept for 10 days. Although colour change of the oil was not observable but decrease in flash point, temperature was noted to be 10 °C, which is significant.



Water Acid

Fig.13 Effect of acid and water on oil and bimorph

Effect on the actuation of the bimorph:-

Corrosion of bimorph in case of acid test was significant and observable with naked eye, but in case of water inclusion, it was not observable.

Model Proposed

The final setup that is proposed includes both the Shape memory alloys , Cu-Al-Ni Bimorph and NiTi Spring , which improves the temperature sensing capability .

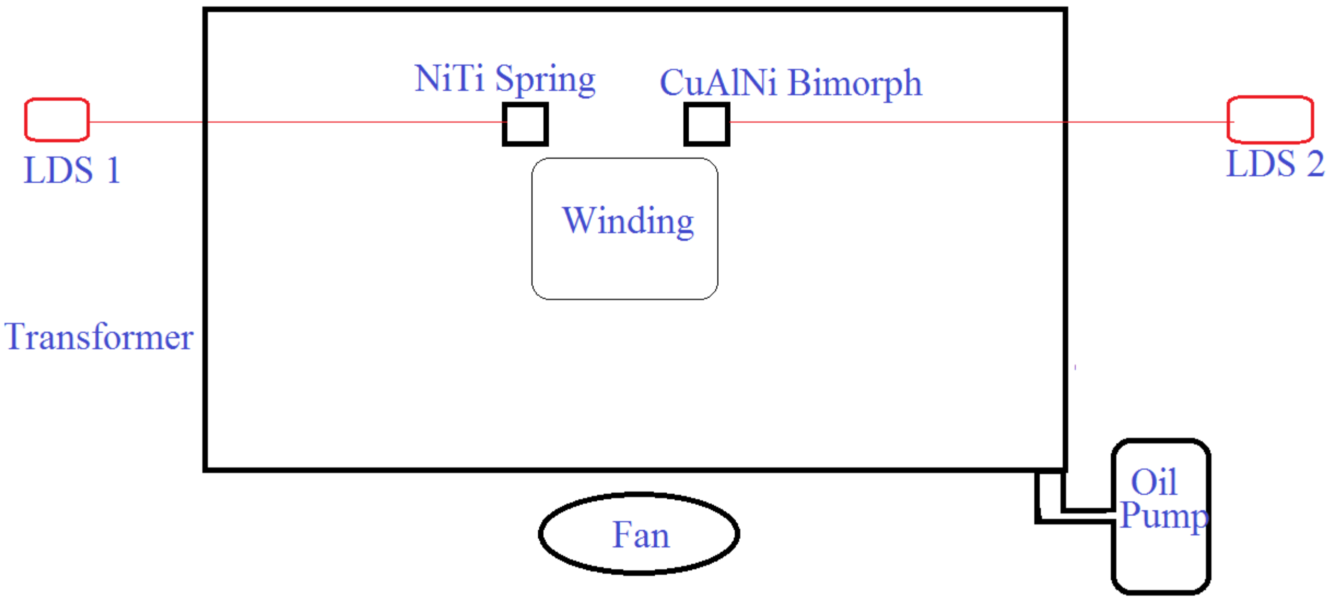
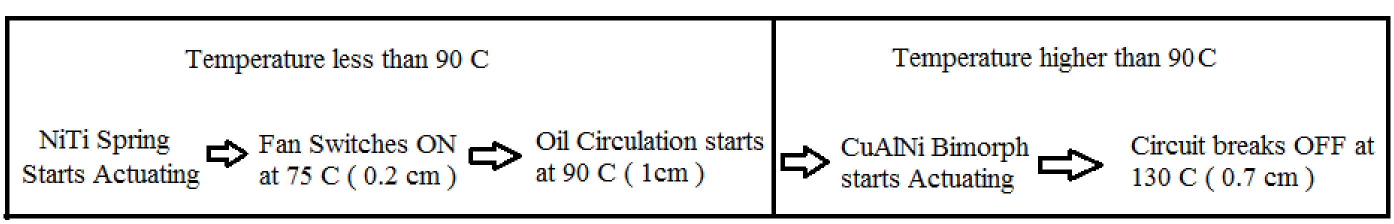


Fig. 14 Final Model Proposed

- In the temperature range, less than 90° C the NiTi springs actuates and helps in temperature sensing and gives reading to Laser Displacement Sensor 1 .
- In the temperature range, more than 90° C the Cu-Al-Ni Bimorph starts actuating and helps in temperature sensing and gives reading to Laser Displacement Sensor 2 .



Conclusion

- Temperature sensing at Low temperature can be done successfully by NiTi Spring with Sensitivity 0.29 mm/°C

Ni-Ti Spring Property	
Range	45 °C – 90°C
Max Displacement	15 mm
Sensitivity	0.29 mm/°C

Table 4: Ni-Ti Spring Property

- Temperature sensing at High temperature can be done successfully by Cu-Al-Ni Bimorph with Sensitivity 0.2 mm/°C

Cu-Al-Ni Bimorph Property	
• Range	• 90 °C – 150°C
• Max Displacement	• 10 mm
• Sensitivity	• 0.2 mm/°C

Table 5 : Cu-Al-Ni Bimorph Property

- Cu-Al-Ni Bimorph is tested for 22 cycles and NiTi spring for 15, there were no significant changes in their actuation.
- Using both, Cu-Al-Ni Bimorph & NiTi Spring (as in the model proposed) improves the sensing of oil temperature.

Scope for future work

- Profound study of Effects of Contamination on Cu-Al-Ni Bimorph will be done. Compositions can be changed in Cu-Al-Ni Bimorph easily and that composition will be selected which will be having less effect of contaminations.
- Use of contact-type sensing element like strain gauge will be implemented. When the Bimorph gets flattened it experiences tensile stress which can be calculated by the help of strain gauges and then the strain value will be calibrated to temperature value of oil.

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- A GUIDE TO TRANSFORMER OIL ANALYSIS *BY I.A.R. GRAY Transformer Chemistry Services*
- RECENT DEVELOPMENT IN TRANSFORMER WINDING TEMPERATURE DETERMINATION *Jean-Noël Bérubé, Jacques Aubin W. McDermid Neoptix Inc. Manitoba Hydro*
- THE EFFECT OF TEMPERATURE AND TEMPERATURE RISE TEST OF DISTRIBUTION TRANSFORMERS *Jaroslav LELÁK, Michal VÁRY, Juraj PACKA, Eduard FIRICKÝ, Terézia SKORŠEPOVÁ*