Tandem Technique for Fluid Testing

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Abstract: A spectrometer's analytical sample stand is modified to incorporate a conductivity sensor to measure the electrical properties of liquids prior to spectrometric oil analysis (SOA). The sensor is positioned either in the bottom of the fluid sample container or in a probe dipped in the oil container. The sensor configuration is designed for high sensitivity by using coplanar electrodes of a highly conductive material such as copper with large surface area sheathed in a protective alloy material and mounted on a nonconductive substrate. The sensor electrodes are on the order of several hundred micrometers in width and positioned very closely so that the distances between them are on the order of their width. Any small changes in the conductance of the oil sample can easily be detected. The electrodes are connected to a circuit where the signal is integrated and printed a few seconds prior to initiation of SOA. Conductance measurements provide values proportional to the magnitude of oil degradation. A fresh oil of the same formulation as that of the used oil being measured may be used to establish a precise zero baseline and any deviation from this value is indicative of thermal and oxidative stressing of the oil.

Key Words: Condition monitoring, conductivity, electrical properties, lubricant degradation, thermal stressing.

Introduction: Fluid condition monitoring is a technique that involves the analysis of, e.g., a lubricant in field use for the purpose of assessing either its level of degradation or its residual capacity to perform some important tribological function. Changes in engine parameters or conditions which can affect the lubricant itself may or may not be coincident with changes in the level of wear debris in the lubricant. For example, a lubricant ages or degrades in normal operations, sometimes to unacceptable level without any abnormal operation, of the engine. Thus, monitoring can be used to assist in the determination of the proper interval for oil changes. The condition of the used oil is determined by detecting changes in certain chemical or physical properties of the oil caused by degradation of the oil basestock or depletion of the additive package. For properly running engines, the physical properties or chemical composition of the oil change at a certain rate, generally quite minimally, until the additive package is depleted. When abnormal operating conditions occur, e.g., an increase in aeration rate of the oil (excessive seal leakage, deteriorated "O" ring, cracked diffuser cases, etc.) and/or an increase in oil temperature, the rate of oil degradation increases and the physical properties and chemical composition of the oil change commensurately. In these cases, lubricant monitoring can identify abnormally operating turbine engines which cannot be identified by the more frequently encountered monitoring of wear debris. In these situations, detections in lubricant condition supplement wear metal analysis in detection of atypical mechanical system operation.

Background: While a relationship exists between the degree of oxidation degradation and electrochemical properties of a lubricant, electrochemical measurement techniques of used oils is complicated by the effects of different additives and basestocks [1]. Orudzheva [2] reported that the electrical resistance, dielectric constant, and dielectric loss of base lubricating oils were similar but were changed by various additives. Keller and Saba [3] used a dielectric constant tester, which measures changes in the dielectric constant of a lubricant, to analyze gas turbine engine lubricants that had been stressed in laboratory oxidation tests. The data were evaluated with respect to total acid number and viscosity values of the lubricants and displayed meaningful correlation when evaporative loss of the lubricant was minimal.

Cyclic voltammetry is a technique which determines the concentration of specific compounds or groups of compounds by measuring the current generated from their electrochemical oxidation or reduction [4]. It is based on the quantitative measurement of the reduction wave generated from both the original and generated antioxidant species in the oil sample. A relationship was shown to exist between the logarithm of the wave height, which is proportional to the concentration of the various antioxidant species, and the remaining useful life of the lubricant.

The Complete Oil Breakdown Rate Analyzer (COBRA) [5,6,7] has been used as a lubricant monitoring technique for ester based turbine engine lubricants. Any changes in the COBRA readings of used lubricants will depend on the condition of the oil and on its formulation. By detecting the changes in the electrical properties of used oil samples with the COBRA, the United States Air Force was able to identify a total of 30 abnormally operating engines between May 1980 and August 1982 [6]. It has been reported that there is a relationship between the total acid number and COBRA readings and between the degree of degradation and COBRA readings [5,6,7]. Therefore, any changes in the COBRA readings of used lubricants are indicative of the condition of the oil and its formulations.

Many lubricant monitoring based on electrical, electrochemical, chemical, thermal and spectrometric analytical techniques have been developed for hydrocarbon or ester based fluids [1]. Among the techniques investigated in the literature, the electrical property is one of the simplest techniques to adapt in the development of a tandem analysis for the condition of oil and wear metals. Minimal modification of the spectrometer is needed in addition to the initial cost of the sensor and its installation. Verification of the usefulness of conductivity in monitoring oil degradation [5,6] justified its development into this tandem technique.

Description of Apparatus: The analytical device unit is designed to permit electrical conductivity measurements of a fluid in a spectrometer just prior to the spectrometric analysis. Measurements are performed using a probe inside the test sample container before the sample burn for spectrometric wear metal analysis. Figure 1 shows the sample stand of the spectrometer with the conductivity sensor being in the bottom of the oil vessel in one configuration. The contact of the sensor with the connector pins is made when the vessel is placed onto its holder. When the vessel stand is raised into position, a proximity switch initiates the test sequence. If the door to the spectrometer compartment is closed prior to the completion of the conductivity measurement, the electrodes are disconnected and a zero reading is recorded. The electrode disconnect is controlled by a separate relay board which is connected to the spectrometer interlock system. When the test is initiated, a voltage square wave on the order of ± 2.5 V is applied to the electrode. The applied frequency is about one hertz in order to minimize capacitance effects. Current, on the order of less than one microampere, through the oil is detected, rectified and filtered. Since the current tends to be small, a gain of approximately ten million is used. A delay of five seconds is needed to stabilize the reading. After this delay, a total of several hundred data points are made and averaged.

The data are processed by a built-in microprocessor. Once the processor has averaged the readings it converts the data to an RS-232 format and sends the results to the printer. The fluid assessment takes less than six seconds. Control of the printer is returned to the spectrometer and the wear metal test proceeds.

Figure 2 is a photograph of the oil vessel in the sample stand while Figure 3 shows another configuration of the conductivity sensor where the sensor is a probe dipped in the oil. The former configuration is preferred because the oil shields the sensor from the dynamic sparking activity of the discharge during the atomic emission wear metal analyses. The sensor is a long planar electrode of arbitrary geometry. Its sensitivity is dependent on the surface area which in turn is proportional to the length and width of the electrode. Increasing sensor area increases sensitivity of the sensor.

Discussion of the Results: The conductivity sensor is applicable to fluids typically analyzed by the atomic emission spectrometer. Aviation lubricants, internal combustion engine oils, and hydraulic fluids are among the fluids commercially analyzed. Since different classes of oils generate different values of conductivity, the same class of fluid must be referenced when analyzed to get good correlation of data. A fresh lubricant, similar to the oil tested is ideally used as the reference point.

A T-63 turbine engine stand test was conducted to evaluate a 4-cSt ester base lubricating oil. The lubricant was sampled periodically to determine its physical properties as a function of engine test hours. Wear metals, total acid numbers, viscosities, COBRA,

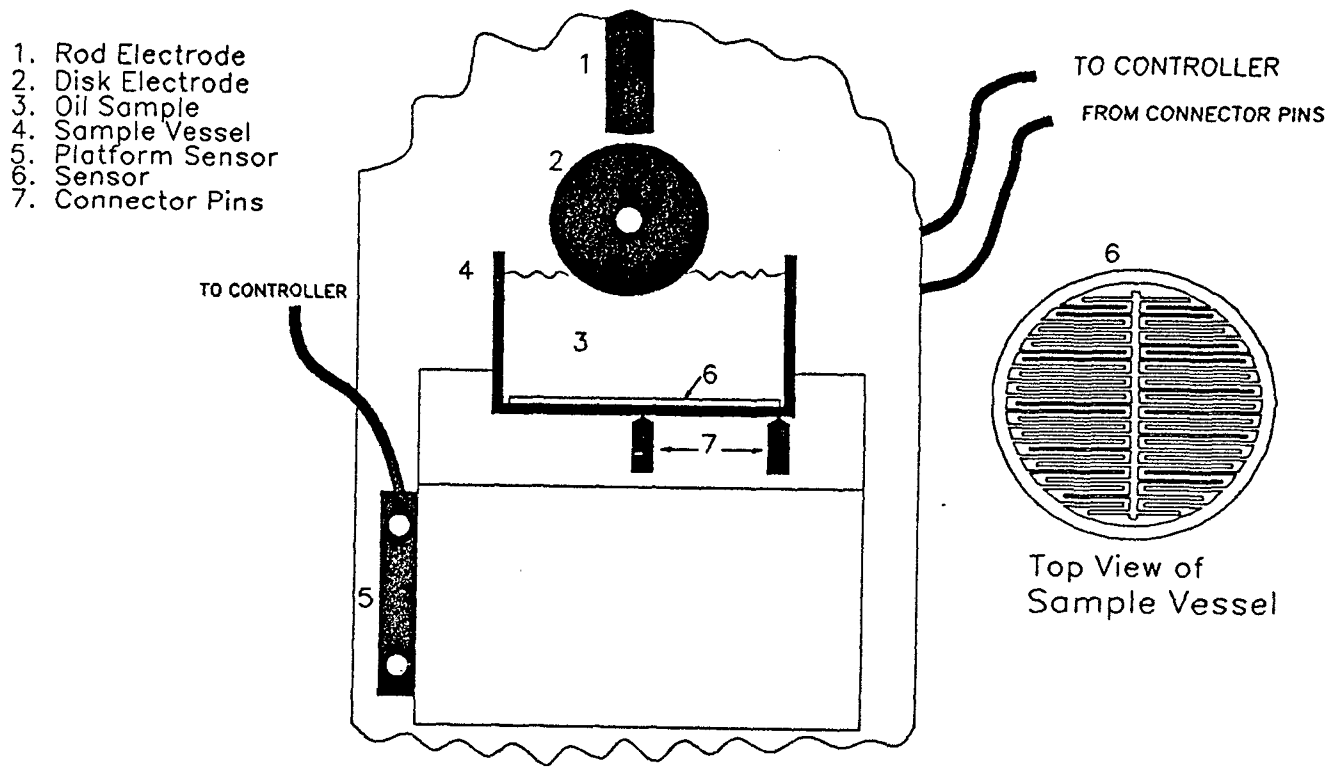

Figure 1. Schematic of Coplanar Conductivity Cap Sensor and Analytical Sample Stand

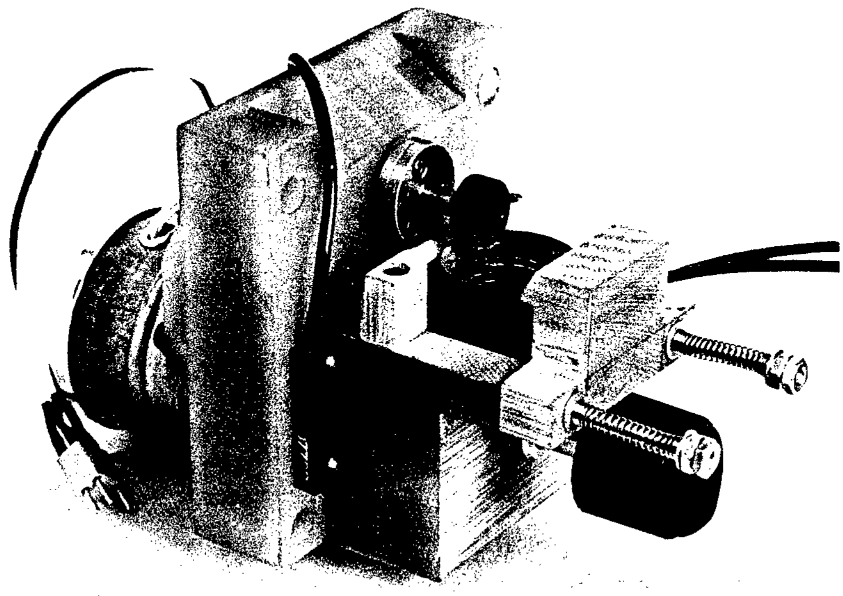

Figure 2. Cap Coductivity Sensor

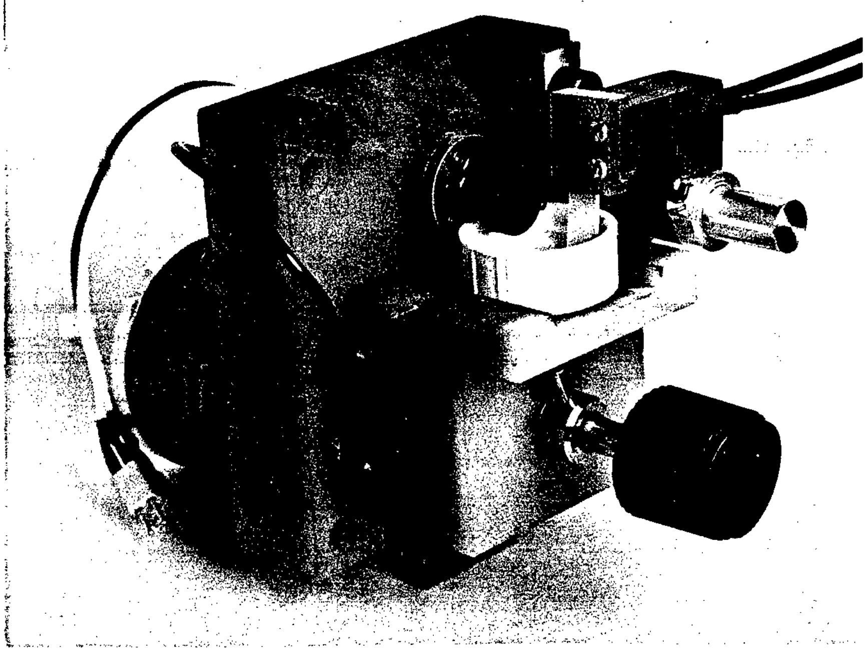

Figure 3. Conductivity Probe

percent lubricant life remaining and conductivity were measured and compared (Table 1). For comparison, the above readings are plotted versus the first 65 hours of the test [Fig. 4]. There was no appreciable increases in wear metals indicating no problems with oil wetted components. Also, the changes in viscosities and TAN values were not significant indicating no appreciable oxidative degradation of the lubricant. However, the basestock degradation seen from the percent basestock remaining study, as shown in the section below, occurs as a result of the thermal stressing of the lubricant and seem to contribute to the significant increases in COBRA and conductivity values. A good correlation is shown below COBRA values of 80 for the first 40 hours of engine testing (Fig. 4). Beyond this testing time the conductivity cup values accelerate at a faster rate than the COBRA. The conductivity data were also correlated with percent basestock of the lubricant remaining, i.e. the lubricant that is not consumed by the high temperature stressing. The results showed a definite correlation in spite of oil make-up during the course of engine test. After the engine test, it was confirmed that the high conductivity and COBRA values were the results of one of the bearings experiencing abnormally high temperature.

A collection of "black oil" samples from gas turbine engines that had been analyzed by COBRA were analyzed for conductivity using the subject device. A "black oil" is an oil that has experienced high temperature beyond its capability in a gas turbine engine and becomes visibly darkened or "black" due to the build-up of carbonaceous material as a result of thermal-oxidative stressing. Conductivity and COBRA values plotted in Figure 5 show a high degree of correlation between the two techniques indicating that conductivity can reliably measure thermal-oxidative stressing of the lubricant in authentic used oil samples.

Oil sample collected from commercial turbine engines were also analyzed by COBRA and conductivity. In spite of the scatter in the results shown in Fig. 6, one can still observe some degree of correlation between the two techniques.

Conductivity of aircraft mineral based hydraulic fluid and aircraft or automotive mineral based lubricating oil was measured as a function of stressing time. The data were also compared with the COBRA. During the 24-hour testing period, the fluids were periodically sampled to measure the changes in electrochemical properties. For the hydraulic fluid, there was a slow increase in conductivity which accelerated after the 8-hour test period. However, COBRA values did not significantly increase until the 16th hour of testing. This is a good indication of how sensitive and predictable this technique is. For the mineral oil, there was a dramatic decline in conductivity after the first two hours of testing followed by a period of no change and then a significant decline after the 16th hour of testing. COBRA values agreed by showing a dramatic decrease. The data establish the capability of the subject device to correlate with COBRA readings and, therefore, determine the condition of a fluid.

TABLE 1

GAS TURBINE ENGINE STAND TEST USING FULLY FORMULATED ESTER BASE LUBRICANT

Test Time h	**Visc.,cSt** 40°C	**TAN** mg KOH/g	**COBRA***	**Conductance**	**Dielectric**
0	17.69	0	6	29	0
8	18.03	0	41	168	0
16	17.98	0	45	228	0
24	17.99	0	55	287	0.6
32	18.13	0.05	66	331	0.6
40	18.25	0.04	66	380	0.6
48	18.16	0.11	76	429	0.8
56	18.29	0.10	90	473	0.8
64	18.44	0.09	90	532	0.9
72	18.40	0.08	87	566	1.0
80	18.54	0.08	90	602	1.0
88	18.48	0.10	88	629	0.9
96	18.43	0.09	94	649	1.1
104	18.52	0.12	96	677	1.2
112	18.50	0.12	100	693	1.3
120	18.59	0.14	104	718	1.1
128	18.69	0.17	110	768	1.2
136	18.61	0.20	107	789	1.2
144	18.64	0.20	116	796	1.3
151.3	18.67	0.23	122	803	1.4
159.3	18.71	0.20	115	842	1.4
168	18.75	0.21	126	844	1.5
174.7	18.86	0.22	126	870	1.5

*COBRA= complete oil breakdown analyzer

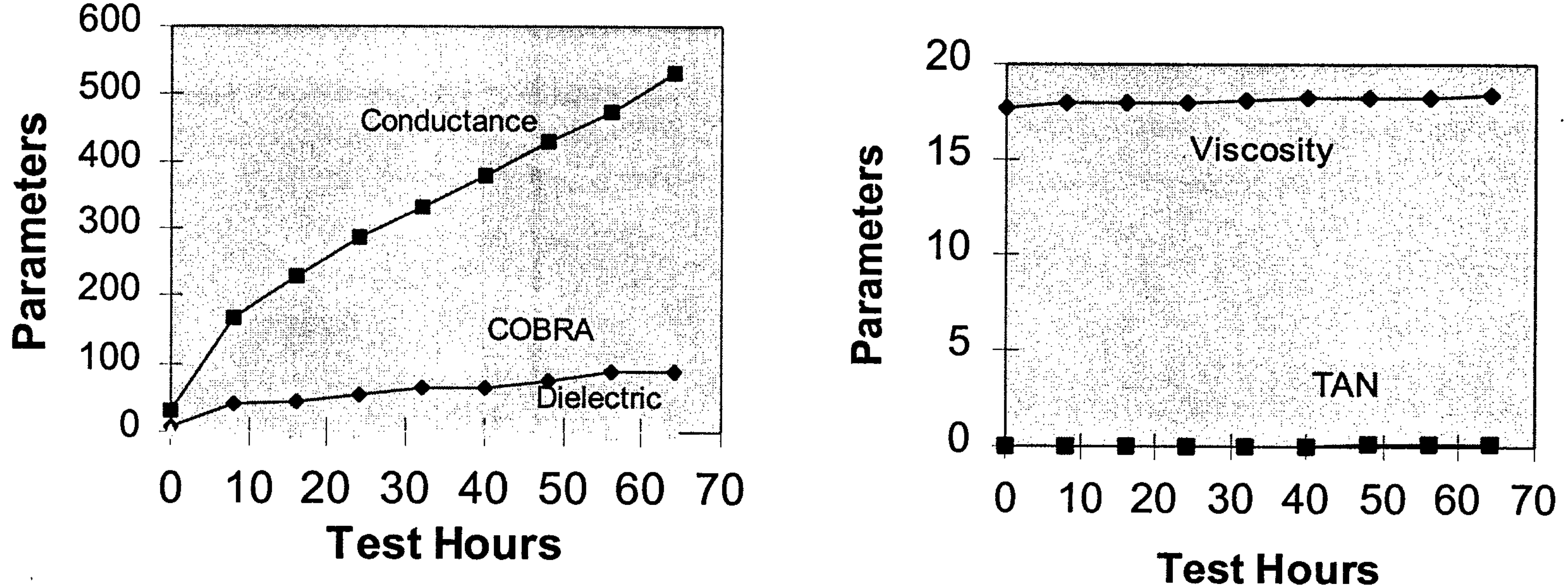

Figure 4. Gas Turbine Engine Stand Test for 4-cSt Fully Formulated Ester Base Lubricant

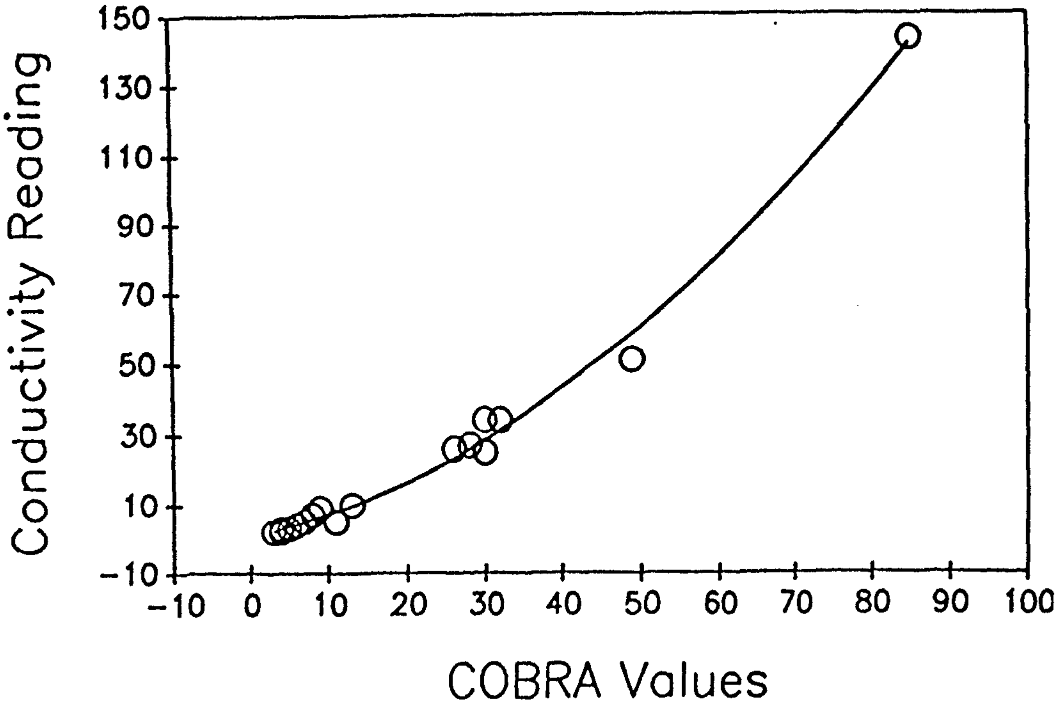

Figure 5. Conductivity Relationship to COBRA Values for Used Gas Turbine Engine MIL-L—7808 Lubricants

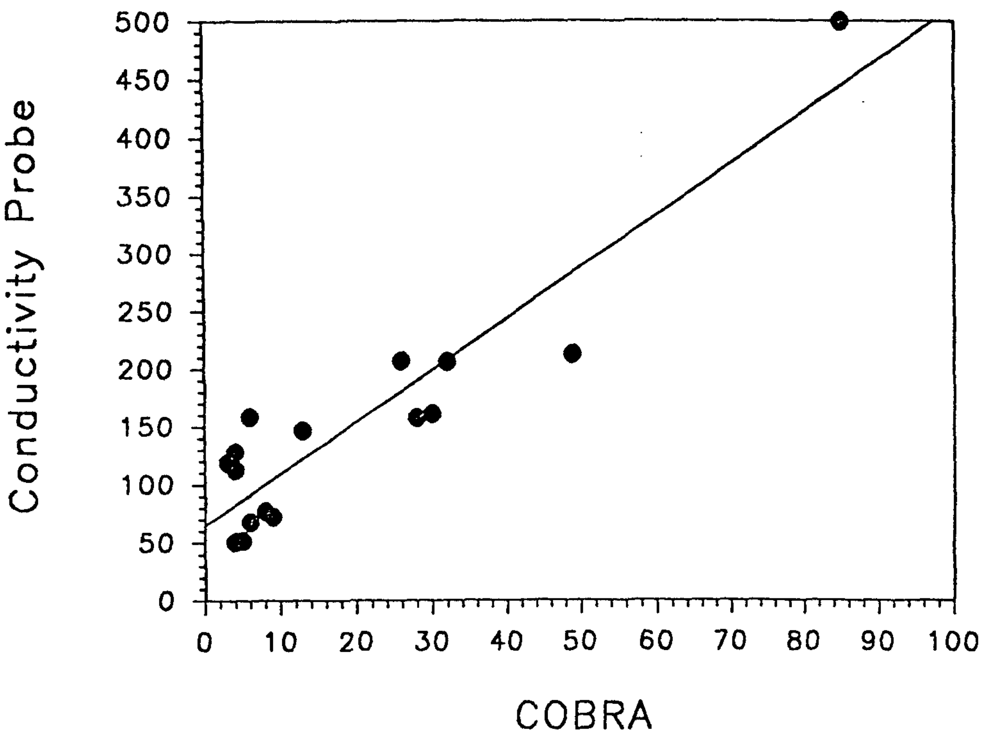

Figure 6. Conductivity Relationship to COBRA Values for Used Commercial Gas Turbine Oils

Based on established practices where COBRA has been used to determine the condition of turbine engine ester lubricants [5,6,7], the correlation of COBRA and conductivity of lubricant samples establishes the merit of the subject spectrometric device in measuring lubricant condition.

In conclusion, the tandem technique measures the electrical property of the fluid and wear metals. These measurements are made sequentially and with minimum sample handling or modification. Traditionally, these type of measurements are made on two separate pieces of equipment which is costly and time consuming. The all-in-one technique gives a fast turn around results with no additional consumable items. Its applicability has been demonstrated and correlated with other existing techniques.

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