Generation of Static Electricity During Oil Filtration

Filters have been widely used to protect hydraulic and lubricating systems from harmful contamination. But one still can have hydraulic problems due to contaminants such as oil oxidation products which cannot be removed by fine pore filters. Oil and fibers for fine filter elements are both dielectric. There is a high possibility that static electricity will be generated when oil passes through fine filter elements.

The authors have invented a test device to measure the potential of the oil and filter housing by an electrometer. This investigation demonstrates that a mechanical filter element generates static electricity by friction with oil and that the static electricity causes spark discharges in the filter element and possibly in an oil tank, too. The spark discharges of static electricity crack oil molecules.

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INTRODUCTION
Day reported that 85 percent of hydraulic problems are attributable to contaminants in hydraulic oils (1). Mechanical filters are widely recommended to protect hydraulic and lubricating systems (2). Servo valves have become popular for use in hydraulic systems, since they are excellent for accurate control. However, they are very sensitive to oil contaminants and require fine pore filters. However, there are still lots of unsolved problems caused by contaminants.

Lauer and Antal measured streaming electric current through polytetrafluoroethylene filter membranes in the range from 2 to 30 microns. They demonstrated that smaller the pore sizes produced the larger streaming currents. Also, the larger the flow velocity, the larger the streaming current (3).

These studies do not discuss the problems of hydraulic and lubricating oils when they are circulating in machines. There is no doubt that when oil passes through a filter element static electricity will be generated and accumulated on the filter element and in the oil. This current is small but the potential is high. Accumulated static electricity will be discharged with a spark between the electrified filter material and any conductive material close to it in the filter element. It is not evident that spark discharges of static electricity happen inside the filter element. The authors cut and examined several used pleated type filter elements. They found evidence of spark discharges of static electricity between the dielectric filter material and the sharp edges of the punched holes of the center core of a filter element. There is a possibility that static electricity generated when oil passes through fine pore mechanical filters can crack oil molecules and produce new contaminants. There is also a possibility that spark discharges of static electricity will be caused between the electrified oil and the sharp end of the pipe submerged in oil in an oil tank.

This paper demonstrates that a mechanical filter can generate static electricity by friction when oil passes through a filter element and predicts a possibility that the accumulated static electricity is discharged with sparks in a filter and in an oil tank.
TEST APPARATUS

Common Test Apparatus

The general view of the test apparatus is shown in Fig. 1. The apparatus consists of an oil tank, a pump with an electric motor and a test filter. The oil tank, the pump and the test oil cleaner are connected by vinyl hose with 6 mm inside diameter. As it is impossible to directly measure the potentials of the electrified filter element, the filter housing was insulated by installing on a poly-tetrafluoroethylene plate. The oil tank and the pump are grounded to release electric charge from the test oil.

Measurement of Potentials

When the static electricity on a substance is measured, the noises from the atmosphere have to be shut off. For this reason, we used a combined unit of Faraday cage with 27.0 pF capacitance and a commercially available electrometer as shown in Fig. 2. In order to maintain a constant oil flow velocity with which oil passes through the test filter element, a three way valve was fixed at the outlet of the test filter housing for oil sampling.

The electrometer is detachable. The potentials of the electrified filter housing was measured by the detached electrometer at a distance of 50 mm from the filter housing.

The room temperature was 25 ± 1°C and the temperature of the oil passing through the filter was 35 ± 2°C, when the potentials of the oil and the filter housing were measured.

Test Oil

Naphthenic base transformer oil with 7.1 cSt at 40°C was used for the filtering test. Turbine quality, ISO 32 grade R & O lubricating oil was used for the spark discharge test in a beaker. The higher the oil viscosity, the higher the oil friction. In order to perform tests at room temperature without heating the oil, naphthenic base transformer oil was selected for filtering tests.

Fig. 1—Schematic diagram of electrification test apparatus.

Fig. 2—Faraday cage and electrometer set to measure potential of oil and filter.

Test Filters

The following two filters were tested; a nominal 2 micron polypropylene depth type filter and an absolute 3 micron pleated type filter.

The polypropylene filter elements with two different conditions were prepared for the test; one was dried in a thermostatic oven at 80°C for 24 hours and the other exposed to the humid atmosphere for two weeks.

EXPERIMENTAL TO KNOW THE EFFECT OF OIL FLOW ON POTENTIAL

Tests

In order to determine the effects of oil flow on potential, a filter housing designed for the test of polypropylene depth filter with 0.15 L in volume was used. The filter housing had a narrow passage of a stainless steel pipe and a vinyl hose. The vinyl hose was fixed to the stainless steel pipe at an end of a three-way valve on the outlet of the filter housing. The inside diameter of the pipe was 5 mm and the length was 25 mm. The vinyl hose was 6 mm in inside diameter and 350 mm in length from the stainless steel pipe to the Faraday cage. The volume of the Faraday cage was 0.5 L. In view of relaxation time of static electricity and in view that the oil turbulence with high flow velocity might cause spillover of oil out of Faraday cage, the potentials of oil was measured by taking 0.1 L and 0.2 L oil samples in the Faraday cage.

The potentials of 0.2 L oil were measured without any filter element in the filter housing in the rage of the flow velocity from 0.75 to 5.0 L/min.

Potentials of 0.1 L and 0.2 L oil passing through a grounded dry polypropylene filter were measured in Faraday cage.

RESULTS AND DISCUSSION

The electrometer measures the potential of oil sample in accordance with the following equation (4).

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Fig. 3—Electrification of 0.2 L oil when oil passes through a pipe and a vinyl hose.

\[ V = \frac{Q}{C} \]  \hspace{1cm} \text{[1]}

where

- \( Q \): Electric charge (Coulomb)
- \( C \): Capacitance (27.0 pF)
- \( V \): Potential (Volt)

When the tested oil is electrified, the potential of the oil can be measured by voltage.

The potentials of 0.2 L oil passing through an empty filter housing are shown in Fig. 3. The results suggest that electrification of oil due to friction with the pipe and vinyl hose is negligible until the flow velocity exceeds 4 L/min.

The potentials of 0.1 L and 0.2 L oil are shown in Fig. 4. The potentials of 0.2 L oil were twice as same as those of 0.1 L oil. This suggests that the potential of oil is in proportion to the quantity of oil in Faraday cage. Therefore the potentials of 0.2 L oil are taken in this paper. Besides establishment of same oil quantity, this result may suggest a possibility that the potential of oil in machines having a large volume of oil will be high, even if relaxation time of static electricity is discounted.

EXPERIMENTAL TO KNOW THE EFFECT OF GROUND AND INSULATION OF FILTER ON POTENTIAL

Tests

The potentials of oil were measured with dry polypropylene depth filter, when the filter housing was grounded and insulated by placing on a poly-tetrafluoro-ethylene plate. The potentials of the insulated filter housing were also measured.

RESULTS AND DISCUSSION

The potentials of oil of grounded and insulated filters are shown in Fig. 5 and the potentials of the insulated filter housing are shown in Fig. 6. The test results suggest that the oil was charged positive and the filter negative.

The potentials of oil passing through a grounded filter were higher than those of the insulated one. The results can be understood by considering that a kind of condenser is formed in the filter housing. When the filter housing is grounded, the negative charge goes to the ground and the condenser becomes empty. When the condenser is empty, negative charge can be unlimitedly supplied to the condenser and separation of the electric charge increases. Consequently the supply of the positive charge to oil increases.

When the filter housing is insulated, electric charge supplied to the condenser will be accumulated. If the condenser becomes full, it will not accept additional supply of electric charge. However a part of the accumulated electric charge will be lost into the atmosphere or by relaxation. Then the condenser can accept supply of the electric charge equivalent to the lost one. The electric charge, which was separated by friction but not accepted by the condenser, will be offset with the opposite charge in the oil. It is the reason why the potentials of oil with the grounded filter housing were higher than those with the insulated one as shown in Fig. 5.

All machines are grounded. Therefore we cannot feel any electricity even when we touch any machines. However the
test results suggest a possibility that the oil in the grounded machines is electrified and that the potential of the oil may be high in the oil tank of the grounded machines.

The Fig. 6 indicates that the higher the pump flow rate, the shorter the time to reach the saturated potential. While the potentials of the filter housing were measured, discharging noises were heard periodically. This suggests that the electric charge higher than -50kV is discharged into the atmosphere. The test results indicates a possibility in a working machine that the accumulated electric charge on the dielectric filter element will be discharged with a spark at the nearest sharp point of metal in a filter installed on a grounded machine.

EXPERIMENTAL TO KNOW THE EFFECT OF HUMIDITY ON POTENTIAL

Tests

In order to examine the effect of humidity on potential, a polypropylene depth filter was exposed to the humid atmosphere for two weeks. The potentials of oil and the filter housing were measured when the humid filter was grounded and insulated.

RESULTS AND DISCUSSION

The measured potentials of the oil are shown in Fig. 7. The saturated potentials of the insulated filter housing and the average time to reach the saturated potentials are shown in Fig. 8.

The potentials of oil were substantially lower than those with dry one. The polarity of the electric charge in the oil with the humid filter element was negative at the oil flow velocity of 0.75 L/min but it turned to positive at the velocity of 1.6 L/min and larger. From this test, one cannot tell why the potential of the oil was negative at the velocity of 0.75 L/min and it turned to positive at the velocity of 1.6 L/min and higher. Further study will be worthwhile in this matter.

The potentials of oil were proportionally increased with the flow velocity from 0.75 to 2.4 L/min but they were almost saturated with the flow velocity larger than 2.4 L/min. This suggests that the separated charge will be affected by and offset against the opposite charge in the humid filter element. This also may suggest that a conductive filter element will electrify oil less.

The saturated potentials of the filter housing with a humid filter show in Fig. 8 were a little bit lower than those with a dry filter in Fig. 6. The time to reach the saturated potentials with humid filter was longer than with a dry one. Such difference may come from the absorbed water which has more free ion than mineral oil. A part of the electric charge of oil may be offset with such ions or other carriers which will be adsorbed on the humid filter element. These data suggest that a humid filter reduces both the potentials of oil and the filter housing.

The saturated potential and the time to reach the potentials of ±10 kV, ±20 kV and ±25kV at the velocity of 0.75 L/min in Figs. 6 and 8 show an interesting similarity with the opposite polarity. However one cannot find the meaning yet.

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Fig. 7—Electrification of oil when oil passes through depth dry filter element and humid one.

EXPERIMENTAL OF SPARK DISCHARGE

Tests

To demonstrate spark discharges of the static electricity which was accumulated on a filter element, a pair of electrodes fixed with 1 mm gap on a poly-tetrafluoro-ethylene frame was prepared. One electrode with a flat surface was connected to the filter housing by a high voltage electric cable and the other needle electrode was grounded as shown in Fig. 9. The electrodes assembly was put in the 0.15 L oil in a beaker.

RESULTS AND DISCUSSION

Repeated spark discharges of the static electricity were noticed between the electrodes in the oil in a beaker almost every second at the flow velocity of 4.0 L/min. The interval of spark discharges was shorter at the higher flow velocity. Gas bubbles and traces of carbon came out between the electrodes at every spark. This suggests that oil molecules are cracked by spark discharges of static electricity.

EXPERIMENTAL OF PLEATED FILTER

Tests

The pleated filter was installed on the steel frame and mounted on a poly-tetrafluoro-ethylene pedestal as shown in Fig. 10. As the filter had no pump, an external pump was used for the test.

According to the makers catalog of the pleated filter, the flow velocity of the oil with the viscosity of 32 cSt is about 60 L/min when the pressure drop of the filter assembly is about 98 kPa (1 kgf/cm²). However the tests were performed with the flow velocity in the range 2.6 to 7.4 L/min caused spillover of oil out of the Faraday cage and that oil spillover contaminated the sensor of the electrometer.

The potentials of the filter housing and the test stand were measured during the test at the five points of A to E.

Several pleated filter elements which were used in factories were cut and examined to find some evidence of spark discharges of static electricity in the filter element.

RESULTS AND DISCUSSION

The test results are shown in Fig. 11. The measured potentials of oil were negative, although the polarity of electric charge of the oil passing through polypropylene filter element was positive as shown in Fig. 5. The pleated filters were made of three layers of synthetic unwoven fibers. The details of the materials were unknown. Therefore it is difficult to presume the cause of the opposite polarity.

The shapes of the measuring points on the filter test stand and the measuring direction and the results of measurement were shown in Figs. 12 and 13. The potentials of the flat point were quite different from those of the sharp point although the measuring condition was same. Such difference reflected the electric flux density which depended on the radius of curvature at the measuring points of the test stand and the filter housing. The more sharp, the higher the poten-
Fig. 9—Schematic construction of spark test electrodes device.

Fig. 10—Pleated filter on an insulating pedestal: A, B, C, D and E are measuring point of potential.

Fig. 11—Electrification of oil passing through pleated filter.

The current design of oil circuit

Many machines incorporate filters in the main stream of oil at a suction side or at a delivery side or at the return side. Some machines use by-pass filters. The velocity of the oil flow is high in general in the main stream of oil. The higher the flow velocity, the higher the potentials of the oil and the filter element. Almost all of machines are grounded. It suggests that the potential of oil is high. In view that the larger the oil volume, the higher the potential of oil from Fig. 4 and

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Fig. 12—The shape of the point A, B, C, D and E at which the electrometer pointed.

Fig. 13—Measured potentials at 5 points of A to E on the test stand and the pleated filter housing.

Eq. [1], there are some possibility that the potential of oil in an oil tank will become high and that spark discharges happen between the electrified oil and the edge of pipe in the oil tank from Fig. 13.

From the point of protection of oil and machines and in view of the facts which were investigated in this paper, the current designs of using mechanical filters in the main oil stream may have to be reconsidered.

CONCLUSION

1. Oils are electrified by friction when they pass through filter elements and the potentials of oils increase in proportion to the oil flow velocity.

2. The potentials of oil are higher with the dry filter element than with the humid one.

Fig. 14—Schematic construction of pleated filter.

Fig. 15—Evidence of spark discharges at the sharp corner of punched holes of a pleated filter.
3. The potentials of the oil are higher when the filter housing is grounded than it is insulated.
4. The filter elements are electrified with the opposite polarity of the oils and the electric charge on the filter elements can be accumulated to high level and discharged with spark.
5. Static electricity accumulated on the fibers of fine pleated filter elements will be discharged with sparks between the fiber and the sharp edge of the punched holes of the center core of the grounded filter.
6. From the point of the protection of oil and machines, mechanical filter have a possibility of damaging the oil and the use of mechanical filters on the main oil stream may have to be reconsidered.

REFERENCES